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HOW IT WORKS

SC VIRONMENT T ORY SPACE

DOGS WITH JOBS

MEET THE CLEVER CANINES WITH CAREERS

THE SPACE SHUTTLE

Celebrating the achievements and legacy of NASA's reusable orbiters

HOW WE'LL CURE CANCER

THE GROUNDBREAKING RESEARCH AND INNOVATIVE THERAPIES HELPING US FIGHT BACK

+

SMART METERS
FROST
VIRUSES
MOORE'S LAW
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ALCHEMY
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Future
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+ SPACE PHOTOS **KATHERINE JOHNSON** SILICON VALLEY

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ISSUE 103

WELCOME

The magazine that feeds minds!

"Dogs can use their canine super senses to escape danger, weed out the bad guys and prevent disaster"

Dogs with jobs, page 36

Meet the team...

Charlie G
Production Editor
While I of course don't condone their actions, I can't help but admire some of the ingenious thieves that make an appearance in our heist feature. Find out how they fared on page 74.

Charlie E
Staff Writer
I am really interested in off-road cars and dirt bikes, so I have enjoyed explaining how it all works on page 64. Now my life's ambition is to compete in the famous Dakar Rally!

Duncan
Senior Art Editor
I'd like to see more companies introduce some Silicon Valley work culture ideas over here. Nap areas and ping-pong tables would be amazing!

Laurie
Studio Designer
Our familiar canine friends are remarkably busy animals, from working with the police to aiding the deaf. Turn to page 36 and learn more about the sheer variety of doggy jobs out there!

FOLLOW US... How It Works magazine @HowItWorksmag

In the UK, approximately half of us born after 1960 will be diagnosed with some form of cancer during our lifetimes.

This is a sobering statistic, but a better understanding of these diseases is helping to improve survival rates. Studies suggest that over 40 per cent of cancers are preventable, resulting from lifestyle choices such as smoking, using sunbeds or having a poor diet. Thanks to many years of dedicated research, technological advancements and improvements in detection and treatment methods, around half of the people now diagnosed with cancer will survive for at least another decade.

However, the fight is far from over. Scientists are developing new and innovative methods to prevent, locate and eradicate cancers. Future therapies could even help recruit our own immune systems to root out and destroy cancerous cells. Find out more on page 12.

We hope you enjoy the issue.

Jackie **Jackie Snowden**
Editor

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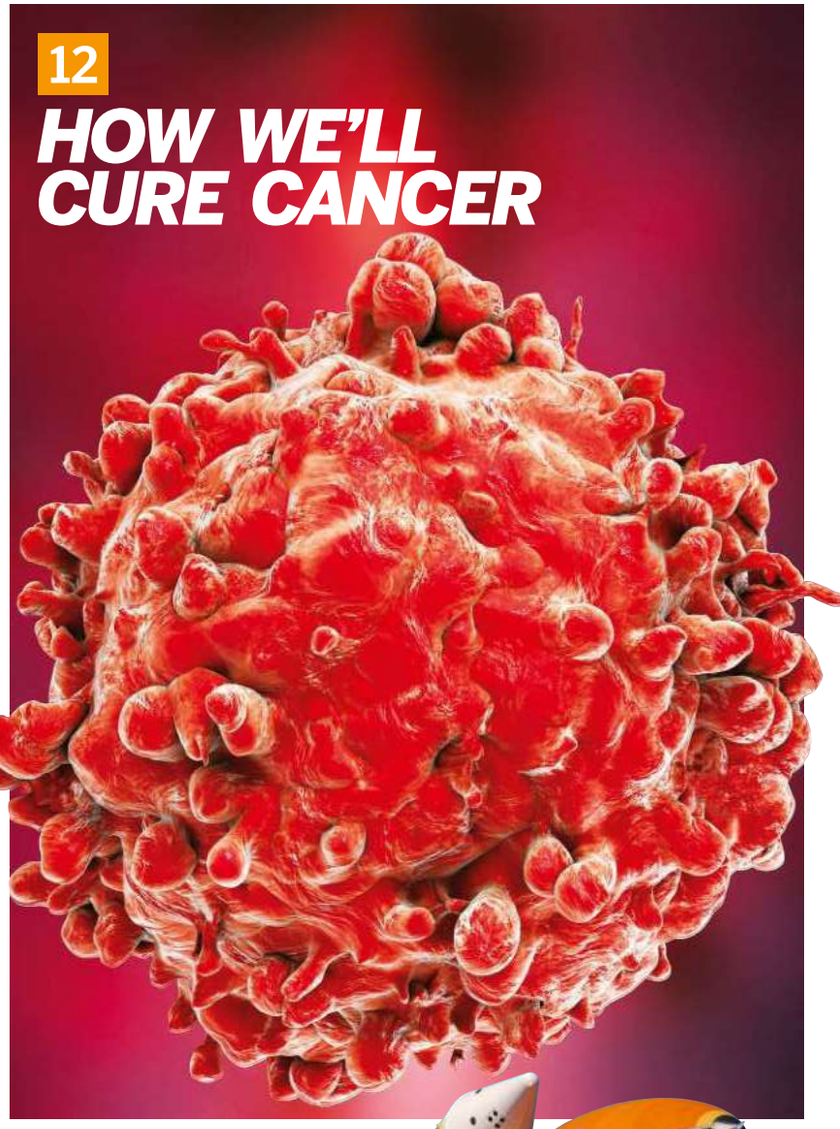

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26 The Space Shuttle

+ FREE POSTERS
• WALKING WITH DINOSAURS
• ZOMBIE STAR
PAGES 49-52

Meet the experts...

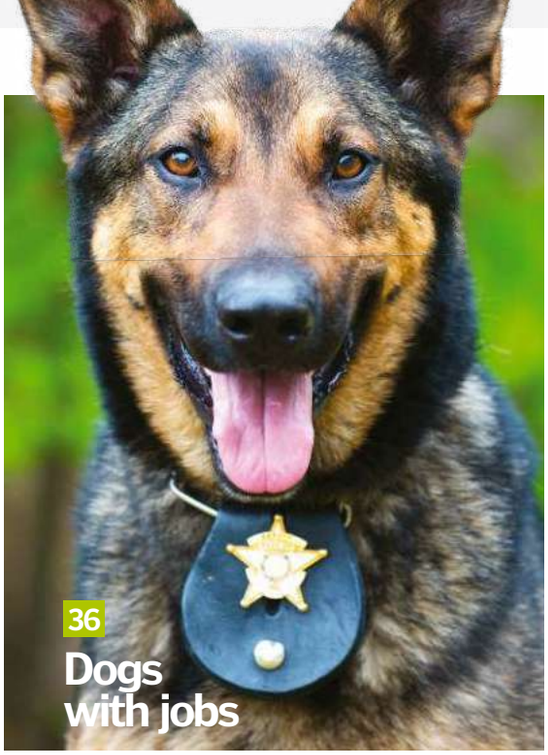
Mike Bedford
This month, Mike explains the history of Silicon Valley. From its humble beginnings, this Californian region has become the tech hub of the world, home to the headquarters of Facebook, Apple and many more.

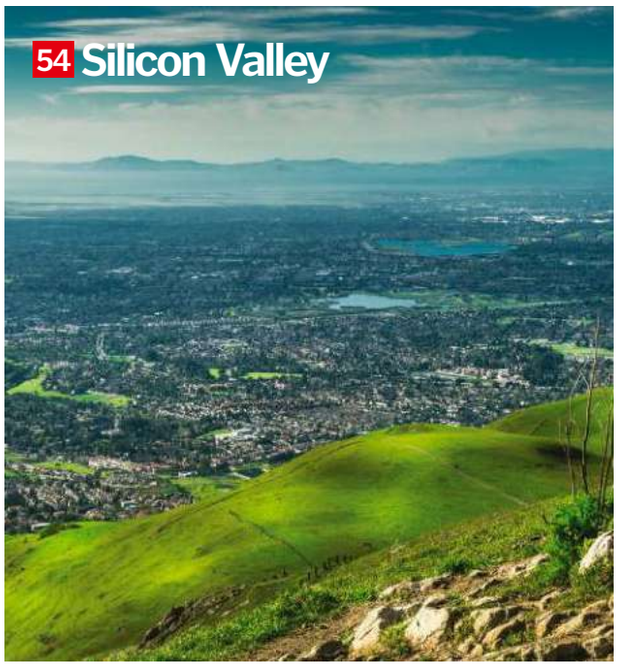
Jonny O'Callaghan
In our space feature, Jonny reveals how NASA's Space Shuttle programme changed exploration; from helping to build the ISS to launching and repairing the Hubble Telescope.

Jo Stass
This month, Jo celebrates the life and work of Katherine Johnson, the NASA mathematician whose valuable contributions to America's early space endeavours helped put man in space and then on the Moon.

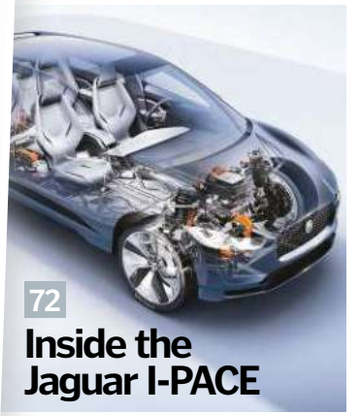
Ella Carter
In our environment section, Ella explains why dogs really are man's best friend. From helping police catch criminals to seeing for the blind, these clever canines play many important roles in our lives.

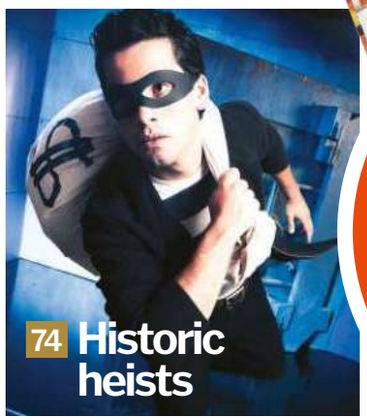
Steve Wright
You'll want to hold on to something or get in the brace position before heading to page 71 in our transport section this issue. Steve takes us on a world tour of some of the world's most terrifying runways.





REGULARS





INJECTABLE TISSUE PATCHES COULD TRANSFORM SURGERY

Scientists have invented a polymer scaffolding to grow human cells that can be injected into the body

The University of Toronto has spent years developing polymer scaffolds that can support the growth of human cells within the body. However, there have been problems developing a way to get them in the right place so they can help to heal damaged tissue and organs.

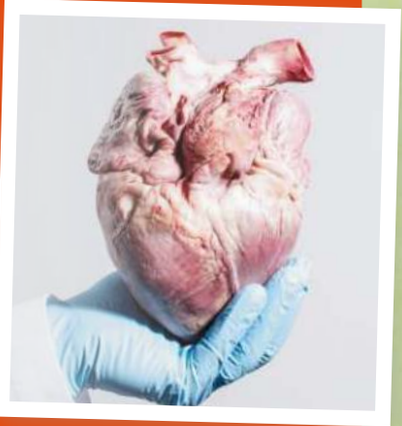
This month saw a breakthrough for the team: they have produced an injectable bandage-like patch imbedded with heart muscle cells that unfolds when leaving the needle. This could revolutionise the treatment of organ damage.

Currently, a patient suffering from a damaged heart caused by a heart attack will have to undergo a large, invasive surgery. But with an already weakened heart this is often dangerous. The development of the injectable patch means that we can start the healing process without the risks of heart surgery on patients who are already weak. The patch is designed to break down over time to allow space for the healthy tissue to grow.

It is expected that this invention will also be improved by the addition of growth factors or drugs to encourage tissue regeneration. The patch has been successful in rats and pigs, and researchers saw that the lab-grown cardiac tissue worked functionally and wasn't affected by being injected. Even so, more research is needed before human clinical trials can start.

Heart attacks

A heart attack is when the blood flow going to the heart suddenly becomes blocked and the oxygenated blood can no longer reach the organ. Most heart attacks are the result of coronary heart disease, which is caused by the buildup of fatty substances in the blood vessels around the heart. If the blockage isn't removed quickly, the muscle starts to die. With 1.5 million heart attacks occurring every year in the US alone, researchers are fighting to find treatments to repair the damage. Currently, the surgical options to treat heart attacks are quite drastic. A coronary bypass can be done to redirect the blood away from the blocked or narrowed arteries, or a thin tube with a balloon at the end can be passed through an artery and inflated to remove the blockage.



The tissue patches unfurl as they are injected via a needle, as shown in this microscope image

NEWS BY NUMBERS

160,000 kph

The estimated speed of the Perseid meteors as they enter our atmosphere

300 years

The estimated age of the *Escarpia laminata* species of deep-sea tube worms

Every 176 years

the gas giants align, providing gravitational boosts, the like of which helped the Voyager probes

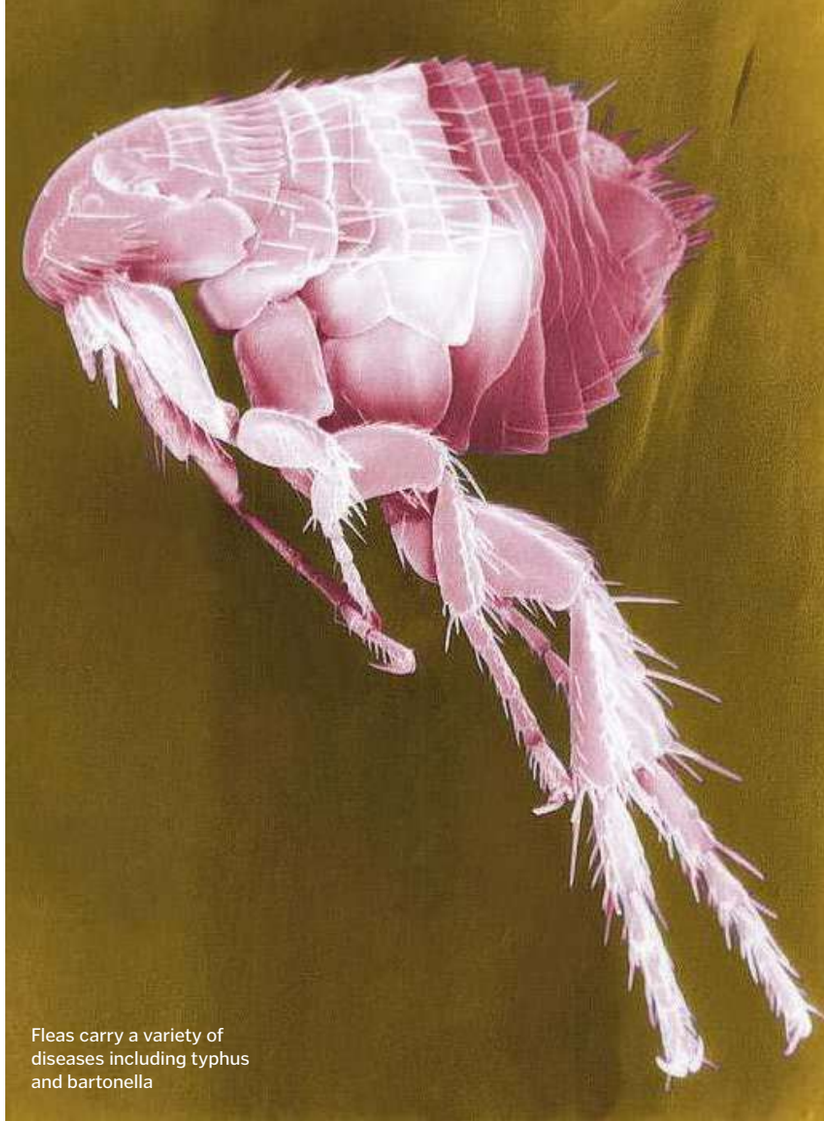
1,000 MW

The amount of power the servers in the proposed Kolos Arctic Circle data centre will use

Plague-carrying fleas found in Arizona

Ancient bacteria continues to survive in the wild

The plague, also known as the Black Death, is caused by a bacterium called *Yersinia pestis* and is spread by flea bites. The bacteria was responsible for killing around 60 per cent of the European population in the 1300s. This month, health authorities in Arizona have reported two counties with fleas testing positive for the bacterium. Is this anything to worry about? Probably not, because we can treat the disease easily these days. But it does serve as a reminder that these ancient bacteria are still present in our world and we need to monitor them and be vigilant to prevent outbreaks.

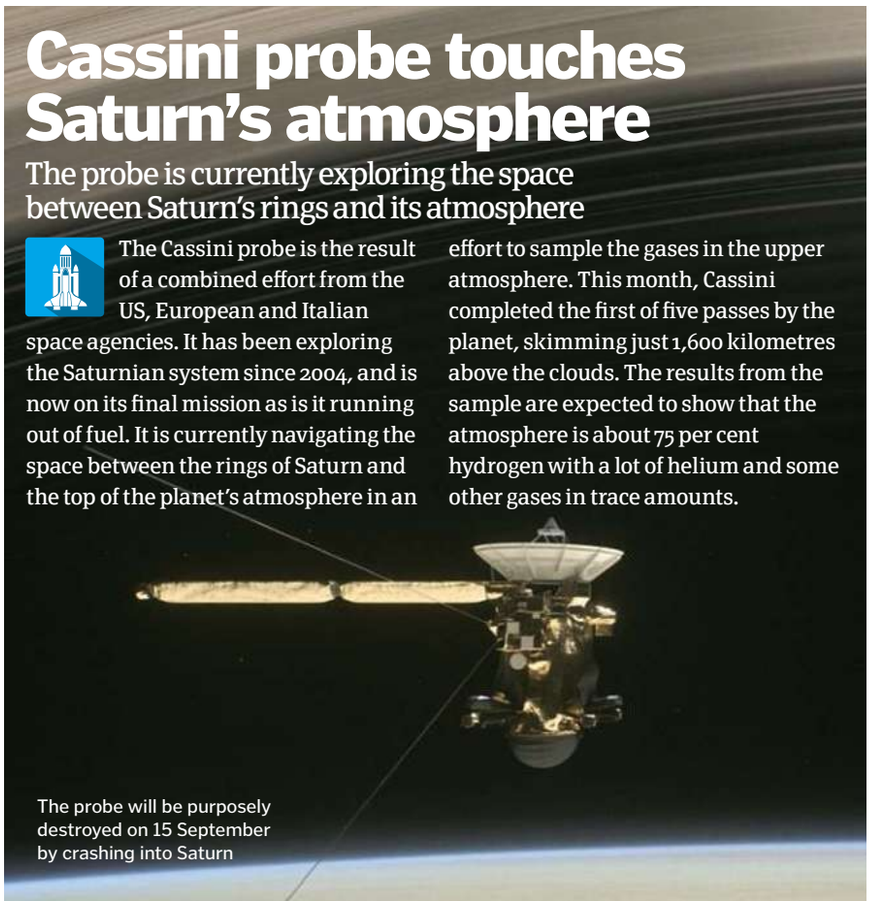


Fleas carry a variety of diseases including typhus and bartonella

Cassini probe touches Saturn's atmosphere

The probe is currently exploring the space between Saturn's rings and its atmosphere

The Cassini probe is the result of a combined effort from the US, European and Italian space agencies. It has been exploring the Saturnian system since 2004, and is now on its final mission as is it running out of fuel. It is currently navigating the space between the rings of Saturn and the top of the planet's atmosphere in an effort to sample the gases in the upper atmosphere. This month, Cassini completed the first of five passes by the planet, skimming just 1,600 kilometres above the clouds. The results from the sample are expected to show that the atmosphere is about 75 per cent hydrogen with a lot of helium and some other gases in trace amounts.



The probe will be purposely destroyed on 15 September by crashing into Saturn

We might be able to use whole organs from animals to help us treat or cure diseases

Scientists edit DNA of pigs and destroy viruses

The genome of live pigs has been edited to deactivate a family of viruses

The pig genome includes retroviruses that can be passed onto other cells when grown together in culture, a problem which has held back the use of pigs as organ donors. But George Church and colleagues at Wyss Institute for Biologically Inspired Engineering at Harvard University and Harvard Medical School have identified exactly where in the DNA these viruses exist and have then used CRISPR to deactivate all 62 of them. They then successfully grew the pig cells in culture and 100 per cent were virus-free, which is great news for transplant medicine.

GLOBAL EYE

10 COOL THINGS WE LEARNED THIS MONTH

A seven-Earth system is older than our own

The intriguing exoplanet system, TRAPPIST-1, could be up to 9.8 billion years old, more than double the age of our comparably youthful Solar System. TRAPPIST-1 is around 40 lightyears away, and contains seven Earth-sized planets in orbit around an ultra-cool dwarf star. Predicting the system's age will help explain how it has evolved and provide clues as to whether any of the worlds might be habitable.

The world's smallest spacecraft launched

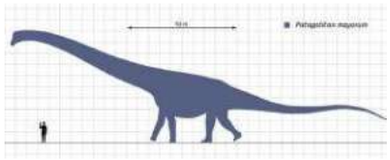
In late July, a set of tiny space probes were delivered to low-Earth orbit by piggybacking on satellite launches. The tiny but fully functional 'Sprites' are part of the Breakthrough Starshot programme to launch interstellar space missions. At just 3.5 centimetres squared and weighing four grams, each Sprite is built on a single circuit board and contains solar cells, a gyroscope, a magnetometer, a radio and antenna. These prototypes will test the capabilities of miniaturised probes, with a view to developing even smaller and lighter 'StarChips'.

Some fish make alcohol to survive

Goldfish and crucian carp can turn lactic acid into alcohol to help them survive in icy cold waters. These fish have evolved specialised proteins that convert lactic acid to alcohol when oxygen levels are low. Researchers studying their remarkable ability to survive found that some goldfish had levels of alcohol that would put them over the legal driving limit in some countries!

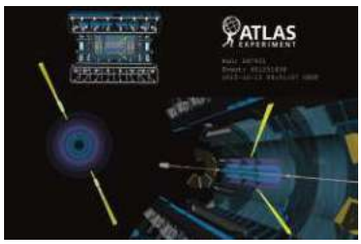
Petrol and diesel cars will be phased out

In late July, the UK government announced that new petrol and diesel cars will be banned from 2040. As part of the Clean Air strategy, it is hoped that this move will help to reduce air pollution and encourage more drivers to switch to electric cars.



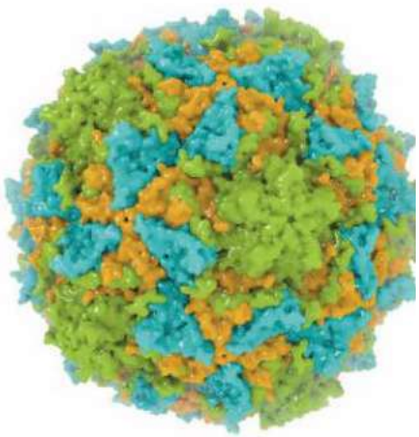
The biggest dinosaur has been slimmed down

The original estimates for the weight of *Patagotitan mayorum* have been revised, from 77 tons to *just* 69 tons. The huge titanosaur's fossil was discovered in Argentina in 2014 and, despite the weight change, it remains the largest known dinosaur to have ever walked the Earth.



Photons can scatter one other

Results from the ATLAS detector at the Large Hadron Collider have revealed the first direct evidence for interactions between photons. Such events are rare, but not impossible; they are predicted by the laws of quantum electrodynamics. After studying more than 4 billion collision events recorded in 2015, 13 candidates for photon scattering — where two light particles interact and change direction — were found.



Plants could help fight polio

A team of scientists have created a new synthetic vaccine against polio that could prove to be a major step towards global eradication of the highly infectious disease. This novel method uses virus-like particles — shells that trick the immune system to respond — and is grown in plants, making it safer and faster to produce the vaccine on a large scale.

Eating less could help you live longer

Scientists have discovered that restricting calorie intake helps keep the body young. In a study with mice, one group were fed a normal diet while another received 30 per cent fewer calories over six months. The processes that regulate our body clocks and metabolism deteriorate naturally as we grow older, but the mice on the restricted diet demonstrated greater protection against these aging effects.

Getting angry could make you happy

In may seem counter-intuitive, but a recent study has found that people report greater happiness when they experience the emotions they desire, whether they be positive or negative. The results suggest that people may feel less satisfaction in their lives overall if they do not get as angry as they think they should do about certain difficult or upsetting situations, such as reading news coverage of horrible crimes.

Big Ben won't chime until 2021

Essential maintenance and restoration work on Big Ben and the Elizabeth Tower means that the bell's famous chimes won't be heard again for another four years. The bell has chimed on the hour for 157 years, stopping only for previous repair works in the 80s and 00s.

INTERVIEW

Colin Furze

We chat with YouTuber Colin Furze about building contraptions, his new book and his life as a plumber, stuntman, inventor, and filmmaker

Hailing from Stamford in Lincolnshire, England, Colin Furze left school at 16 to begin his working life as a plumber. Then he started uploading videos of things he had invented in his spare time. His videos suddenly took off and he found himself with more and more follows and even more ideas of things he could make, not to mention working as a presenter for the Sky1 programme *Gadget Geeks*.

Now Colin Furze is a YouTube sensation with 5 million subscribers. From constructing an apocalypse bunker underneath his back garden, to making a jet-powered motorbike and breaking the Guinness World Record for the fastest toilet, Colin Furze is truly passionate about his wildly inventive creations.

How did you become an inventor with your own YouTube channel?
I use to be a plumber and started making stuff in my spare time. It got picked up by newspapers a bit and somebody approached me to do a TV show as a presenter and that was the tipping point to giving up my job. It was just a hobby first, because when I started uploading videos on YouTube there was no advertising, it was just a place where people could upload videos. I used to like building and making videos, so it was just two things I liked doing that I could do together. I was very fortunate it grew and I've been able to do it bigger and better all the time.

What was the first video you ever uploaded onto YouTube?
It was one of the videos from my youth. Someone told me, "There's this website you can upload videos on — you've got a load of old footage from when you used to mess around in the BMX days." We had filled a super soaker up with petrol and tied it to our bikes so we had these mounted flame throwers. It's not on there anymore sadly, we took it down, but that was the first video I uploaded. The first that went viral was the wall of death I had made out of pallets — all of the other videos before that were ones that I just had around and put them online.

When did you first start building things?
I remember as a kid in primary school trying to make a fake arm so I could go into class and pretend I had broken it. The teacher would come over and I would have an arm all broken and bent into different places. My mum knew about it, and she wouldn't help, but she would never tell me *not* to do it either! I used a pair of her tights to make it look like skin and put a fake hand on the end.

What do you think is the best thing that you have made?
One of my favourites are the magnet shoes because they were built from a load of junk — mostly things you can look at and identify — and bits out of a microwave and ratchet straps. When they were done I was able to walk upside down on the shed ceiling!

Why is it important to get younger people interested in building projects?
You're creating something, at the end you have something to show for it, it's there, and you can do something really cool. I never sell anything I make because I get so attached while I make it.

Where did you get the ideas for what to include in your book?
All of the projects in the book were dreamed up specifically for it. I wanted each one to introduce a new skill, so that you start at the beginning and by the end you would have a skill set: chopping wood, drilling holes, tightening bolts, sawing metal, sawing wood.

Have you ever tried to build something and it's just not worked?
I've had projects that have been difficult. There is this bacon cooking machine that I started last year. I haven't had time to revisit it. It's a load of wheels that the bacon goes around. I have had it work once, but most of the time it just chews bacon up, gets stuck and then smoke starts coming out of it. Some of them are more hard work. The fire tornado at the beginning of the year was just a nightmare, but that was mainly down to the weather. But you don't know this until you've built something and worked out how and why it works and you start to get more familiar with it.

Which records have you broken? Do you see yourself doing any more?
Fastest dodgem, fastest mobility scooter, biggest bonfire. The dodgem was the most recent. I won't be doing any more this year, but whether I do more in the future is a bit random. I'm just waiting for something to strike the right chord, something that suits me and has a good theme I can use to entertain with.

So why did you decide to write a book?
Aside from my videos, I have been trying to inspire people to get into engineering and building stuff, so I thought let's expand on that. One of the biggest problems is that we live in a throw away society — we don't fix stuff, we don't fiddle with a car, we take it to dealership and plug it into a computer. Young people, and adults, aren't learning practical things; we don't tamper and we don't learn, so I wanted to do something about it. So that is what this book is all about — to get young people to learn to make stuff and break down some of the barriers that they have with it.

Among Colin's inventions are a toasting knife and gas-heated slippers

"Have a go, pick things up, if you've got an idea, do something to make it a reality"

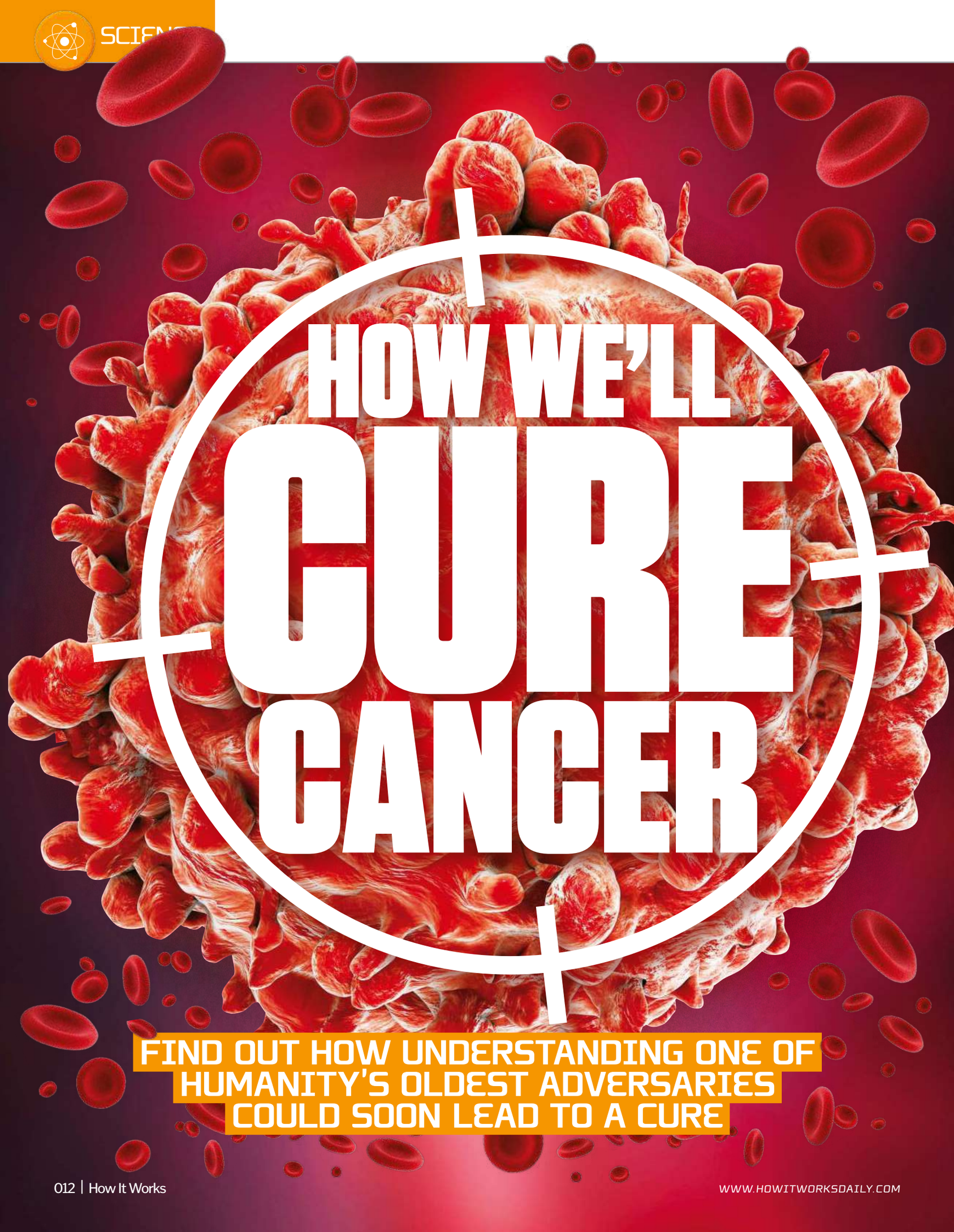
Colin Furze's book, *This Book Isn't Safe!*, is released on 7 September. You can also check out his videos at **youtube.com/user/colinfurze**

What is your favourite activity in your book?
My favourite projects are the Nerf gun firing system or the remote control hose pipe because you can have so much fun when you're finished. My son had a lot of fun with those projects. If anyone would read just one bit I would say read the introduction to inspire others to try and make things so they continue reading. It depends on what sort of person you are. You might already be inspired and want to see what I have made.

And are we allowed to know what projects you will be up to over the rest of this year?
I've had this idea to see if I could score a goal from outside a football stadium. Over the roof of the building. I wouldn't mind doing a Channel crossing, too, but I get sea sick.

What advice do you have for anyone who wants to invent and build things?
I would say just have a go. Have a go, pick things up, if you've got an idea, do something to make it a reality. No matter how simple it is, once you start doing something, you can build on that.

One of Colin's projects saw him construct a 5.5-metre-high AT-AT from *Star Wars*



HOW WE'LL CURE CANCER

FIND OUT HOW UNDERSTANDING ONE OF HUMANITY'S OLDEST ADVERSARIES COULD SOON LEAD TO A CURE

Cancer has been around longer than we have. Traces have been found in 70 million-year-old dinosaur bones, in a 120,000-year-old Neanderthal rib, and in a human skeleton dating back to 1200 BCE. And almost every animal, even sharks and naked mole rats, can get the disease.

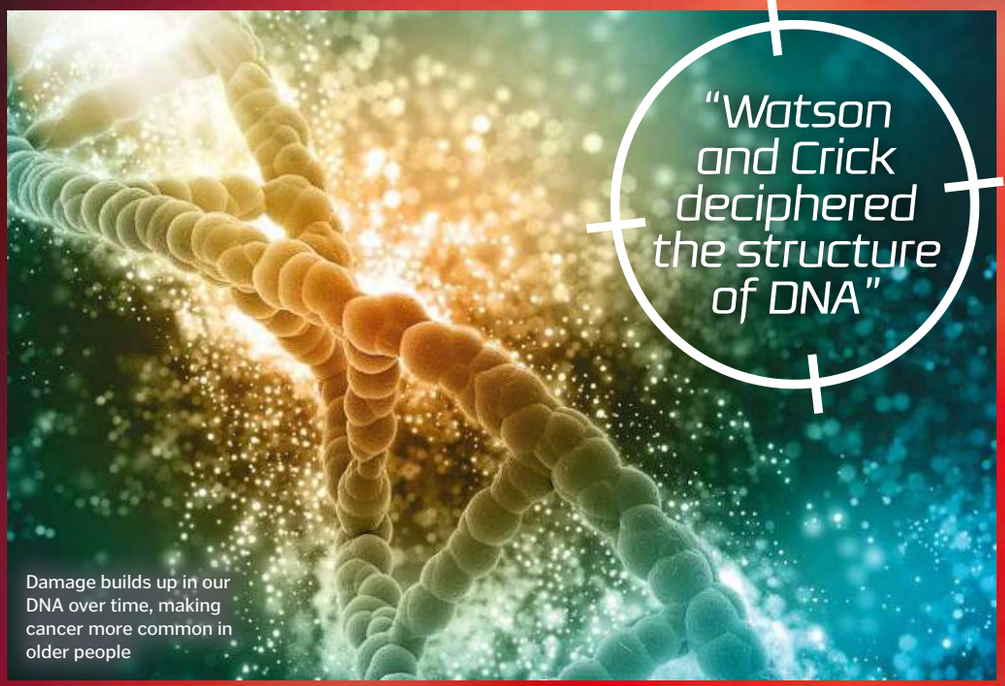
It was once untreatable. Ancient Roman doctor Celsus wrote, "After excision, even when a scar has formed, none the less the disease has returned." Even if the tumours were removed, they kept coming back, but in ancient times we didn't fully understand exactly what we were up against.

By the 17th century, physicians were pointing the finger at a straw-coloured liquid called lymph, which passes through the body in channels that run alongside the blood vessels. And by the mid-1800s, it became clear that cancers were actually made from cells.

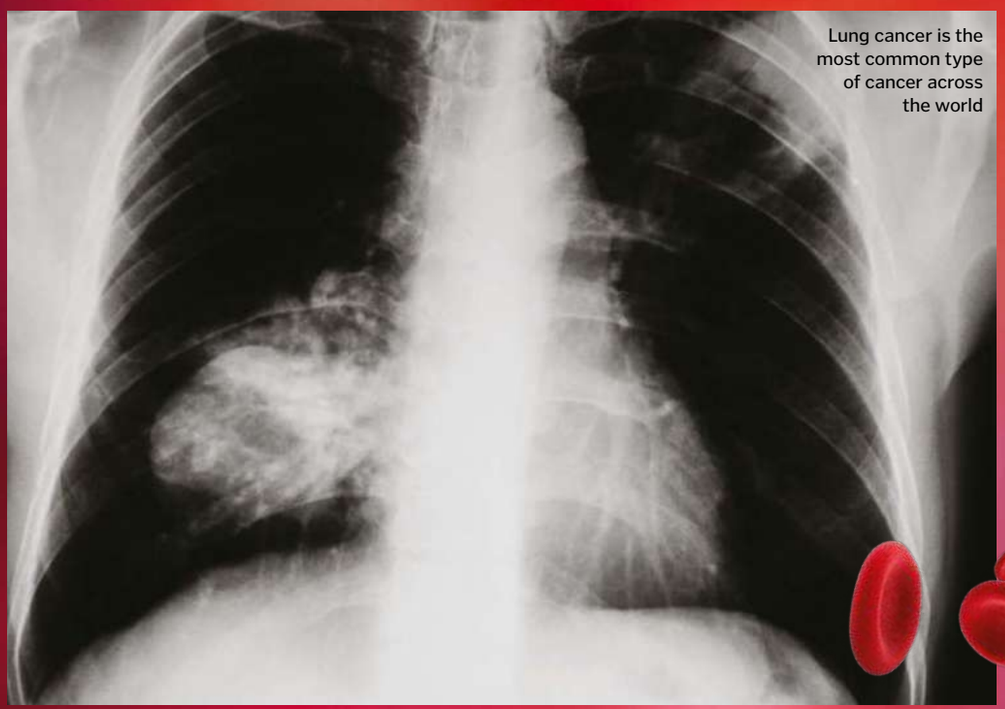
Realising that cancer spread from the original tumour, 19th-century surgeons, with the help of new anaesthetics, started removing more tissue and nearby lymph nodes. Then, at the start of the 20th century, radiotherapy became available to treat irremovable cancers. Nitrogen mustards then became the first chemotherapy drugs after WWI.

Then a massive breakthrough was made. In 1953, James Watson and Francis Crick deciphered the structure of DNA, opening the door to a new era of genetic science. We now know that tumours are made of our own cells but their genes have gone wrong. They change constantly, they evolve to escape treatments, and they hide and spread undetected. And the more we learn, the more we are unravelling their weaknesses.

A century ago a cure for cancer would have been unthinkable, but as research continues survival is rising, and there are many more discoveries yet to be made.



Damage builds up in our DNA over time, making cancer more common in older people



Lung cancer is the most common type of cancer across the world

Cancer statistics

14 million
people were diagnosed with cancer in 2012

22%
of cancer deaths are caused by smoking

8.2 million
people died from cancer in 2012

70%
of cancers happen in low and middle income countries

Cancer is the second highest cause of death in the world

Up to half of all cancers can be prevented by lifestyle changes

Lung cancer is the most common worldwide, followed by breast and colon

The UK has the 23rd highest cancer rate in the world

What is cancer?

The first step to finding a cure is understanding exactly what we're up against

You're made up of an estimated 37.2 trillion cells, each containing an entire copy of your DNA, which consists of 23 pairs of chromosomes and 21,000 genes, written in combinations of four chemical 'letters': A, C, G and T.

The full human DNA sequence contains around 3 billion letters, and the genes are arranged into three-letter 'words' called codons. Each word corresponds to a molecular building block called an amino acid and, when genes are read in order, the words in a gene provide the recipe to build a protein. Proteins are crucial for everything that a cell does, from making energy to deciding when to divide to communicating with its neighbours. But in cancer cells vital genes contain mistakes, changing their proteins and altering the way that they behave.

It takes lots of genetic mistakes to turn a healthy cell into a cancer cell, and they tend to build up over time. A few people inherit genetic faults from their parents, but most occur as we get older. Sunlight, alcohol, radiation and smoking, for example, can all cause harm to our genetic code. But even people with the healthiest lifestyles accumulate genetic faults.

Cells divide for growth and repair, making copies of themselves to replace old cells or to heal wounds. In order to do this, a cell must first duplicate all 3 billion letters of its DNA, and doing this without making a single mistake is a virtually impossible task.

The copied code is scanned for errors, and mistakes are usually fixed before the cell

"Cancer cells keep making copies of themselves with more mistakes"

The hallmarks of cancer

Scientists Douglas Hanahan and Robert Weinberg defined ten distinctive features of cancer cells

They keep growing
Cells normally wait for a signal to divide, but cancer cells make their own growth signals.

They don't stop when told
Cancer cells ignore signals telling them to stop dividing.

They avoid white blood cells
Cancer cells hide from the immune system, preventing the body's natural defences from killing them.

They are immortal
Normal cells stop dividing when they become old, but cancer cells keep on replicating indefinitely.

They create inflammation
Cancer cells hijack immune cells, using inflammation that would normally help to fight against an infection to their own advantage.

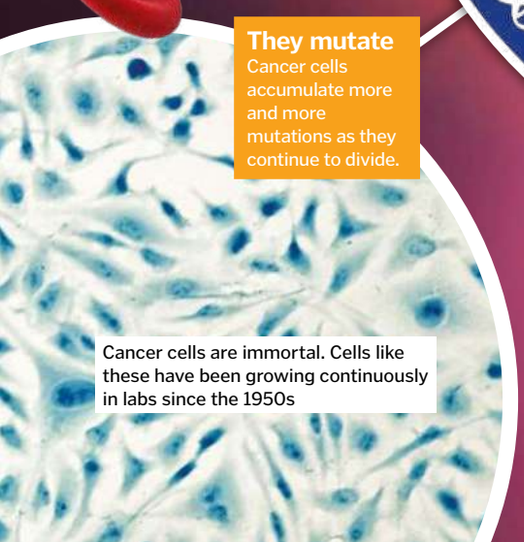
They spread
Cancer cells can spread around the body, creating more tumours in other places.

They set up fuel lines
As tumours grow, they get more oxygen and nutrients by encouraging new blood vessels to form.

They mutate
Cancer cells accumulate more and more mutations as they continue to divide.

They resist death
Healthy cells self-destruct when they are damaged, but cancer cells turn this safety switch off.

They change their metabolism
Cancer cells reprogram their metabolism to keep dividing under conditions that would normally kill other cells.



Cancer cells are immortal. Cells like these have been growing continuously in labs since the 1950s

divides, but sometimes errors slip through and over time they start to build up.

Just as changing the letters in a book would make the words unreadable, changing the letters in the genetic code makes it hard for the cell to make sense of its genes. If letters are changed, deleted, added or moved around, it can completely change the meaning of the genetic words, which in turn changes the proteins that the cell makes.

Built-in safety mechanisms normally tell a cell to self-destruct if it has too many genetic errors, allowing a new, healthy cell to take its place. But sometimes damaged cells slip through the net, failing to repair themselves and resisting the signals to die.

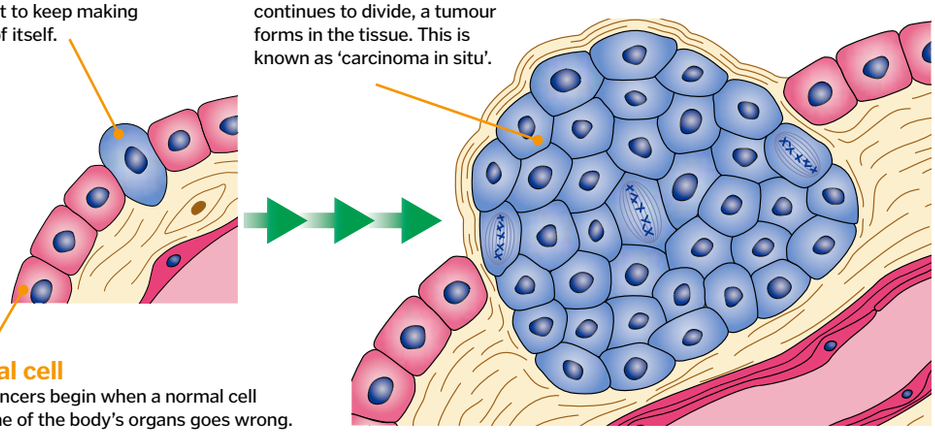
Cancer cells tend to have errors in genes known as 'oncogenes' or 'tumour suppressor genes'. Oncogenes are normally responsible for telling healthy cells to divide, helping with growth and wound repair, but mutations in cancer can cause them to become permanently switched on. Tumour suppressor genes, on the other hand, tell cells to stop dividing once growth or repair is completed, and errors in these genes can cause them to turn off. The result is that the damaged cells divide and divide and divide, piling up on top of each other to form a tumour.

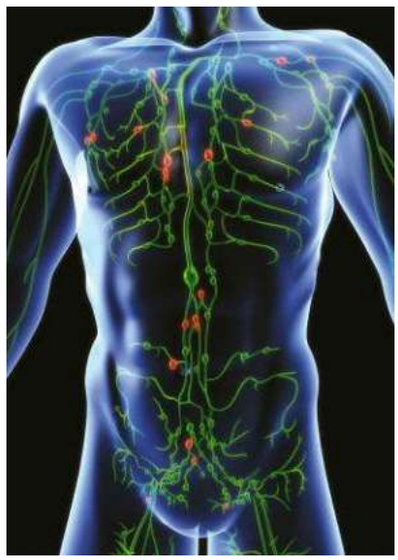
With their safety systems switched off and nothing to tell them to stop, cancer cells keep making copies of themselves with more mistakes in their genetic code, and this leads to Darwinian evolution at a rapid speed. Just as if a wild animal has a beneficial genetic trait it will be more likely to reproduce, if a cancer cell has a beneficial trait it will be more likely to survive.

Cancer cells forget what they are supposed to be doing and gain new abilities, developing traits that allow them to hide from the immune system, survive on less oxygen, and even evade chemotherapy. But, most dangerous of all, they gain the ability to move through the body, spreading to distant places via the blood or lymphatic systems and making new tumours elsewhere. But the more we understand about how cancer works, the better we are becoming at treating it.

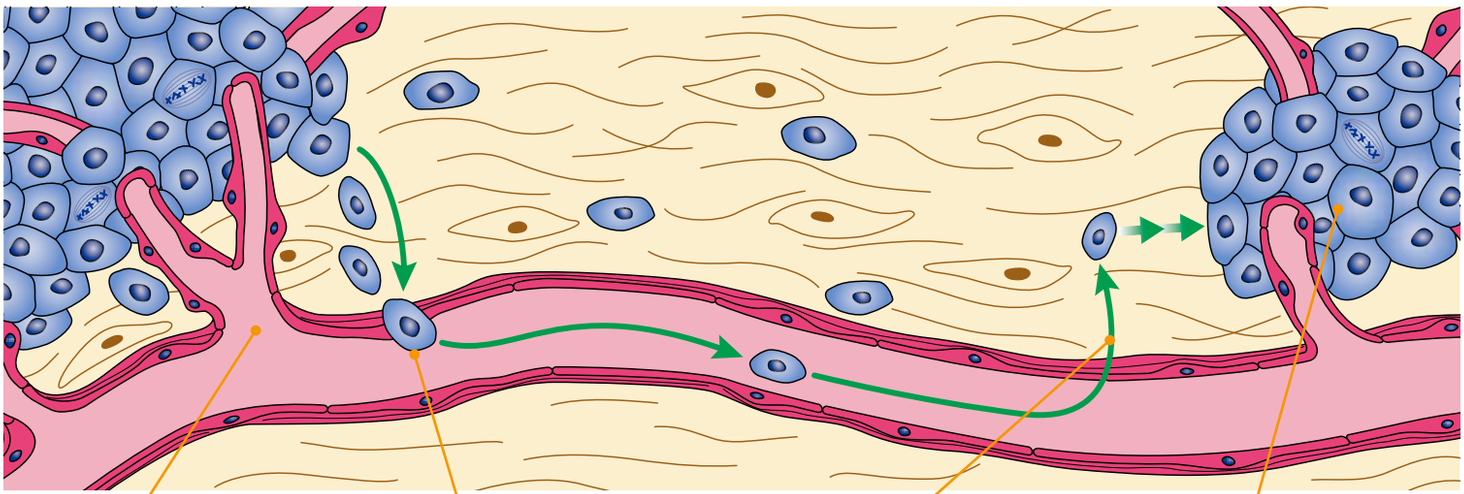
How cancer starts

Cancer begins with a single mutated cell that divides and spreads





Cancer cells can use the lymphatic system to spread around the body



Treating cancer

There are three major types of cancer treatment: surgery, radiotherapy and chemotherapy

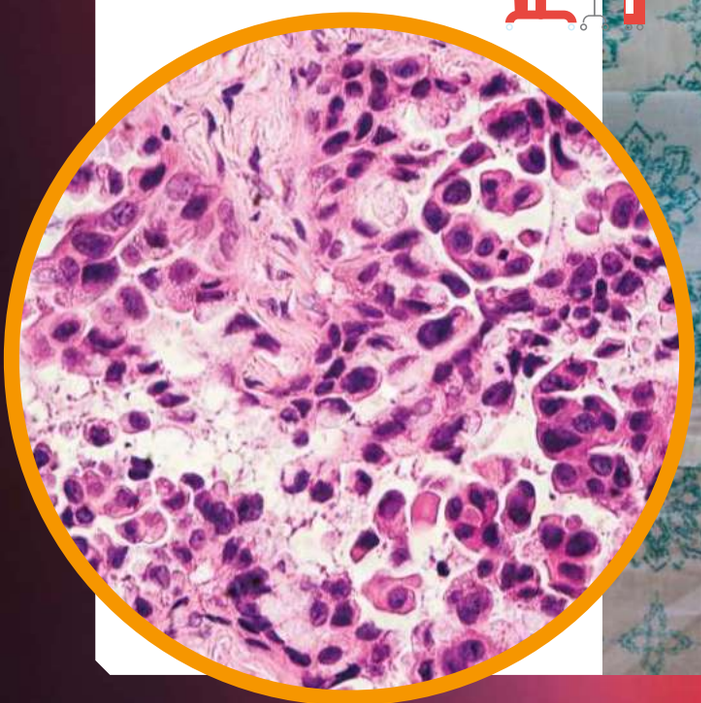
Chemotherapy

The first chemotherapy drug was developed using mustard gas, a chemical weapon used during WWI. Scientists had noticed that the poison killed the fast-dividing cells of the bone marrow, and so they adjusted the weapon to make nitrogen mustard, a treatment that could kill rapidly replicating cancer cells.

Nitrogen mustard belongs to a group of drugs known as alkylating agents, which work by adding chemical units called alkyl groups to DNA. These interfere with the double helix structure, causing the genetic code to break apart.

Other chemotherapies work in similar ways. Heavy metals cross-link DNA, preventing it from being read. Topoisomerase inhibitors stop the DNA helix from unwinding, and antimetabolites work by mimicking molecules involved in copying DNA, stopping the new sequence from being made. Anti-microtubule, or spindle poisons, stop cells from splitting apart, and cytotoxic antibiotics stick to the DNA helix, prevent unwinding, link different strands of DNA together or break DNA into fragments.

These treatments are particularly harmful to cells that are trying to make copies of themselves because they target DNA replication and cell division. This is good for catching fast-dividing cancer cells, but it isn't perfect. Cancer cells aren't always dividing, so some cells manage to escape the treatment, and lots of healthy cells also divide rapidly, too. Hair, skin and bone marrow (which makes blood cells) are all damaged by chemotherapy, leading to side-effects like hair loss, sickness and a weakened immune system.



Pathologists examine images like these to diagnose cancer. This lung tissue should be full of holes

Chemotherapies harm cells that are trying to divide

Radiotherapy

Radiotherapy was developed in the early 20th century and works by bombarding cancer cells with radiation. When the water molecules inside the cells are hit they split apart in a process called radiolysis. This makes highly reactive free radicals with an unpaired electron that attacks bonds belonging to other molecules, setting off a chain reaction that damages DNA.

Radiotherapy causes both strands of the DNA to break close together, a lesion known as a 'double-strand' break. This makes the helix unstable and it starts to unwind. Cells can repair a bit of this kind of damage, but the more radiation they receive, the more likely they are to die.

The most common way to deliver radiotherapy is by using a linear accelerator (LINAC). It uses microwaves to make electrons, which hit a heavy metal to make X-rays. CT or MRI scans are used to pinpoint the exact location of the tumour inside the body, and the X-rays are then shaped to fit the outline of the tumour. This is done by blocking part of the beam using sheets of metal known as a multileaf collimator.

X-rays go all the way through the body, so the machine rotates to deliver beams from all angles, giving the maximum dose where the beams cross over at the site of the tumour, minimising the amount of radiation received by the surrounding healthy tissue.

Linear accelerators rotate to deliver high-energy X-rays into tumours from all angles

Surgery

Surgery is one of the oldest and most effective cancer treatments. If the cancer hasn't spread, surgeons take out the whole tumour and some of the surrounding area in case there are any cells that can't be seen. Nearby lymph nodes may also be removed as these are often the first place a cancer will spread to.

If the whole tumour cannot be removed, surgery can also be used for 'debulking', where as much of the tumour is removed as possible so the rest can be treated with chemotherapy or radiotherapy. Surgery can also be palliative, relieving symptoms when cancer cannot be cured.

Not all lumps are tumours and not all tumours are cancer, so surgery is often used for cancer diagnosis, too. A small sample of tissue, known as a biopsy, is removed and either frozen solid or embedded in wax so that it can be thinly sliced. These slices are stained so that a pathologist can examine the structure of the cells and tissue.

Cancer cells look different under a microscope, creating disorganised structures in normally orderly tissues, and they also display specific molecular or genetic markers that single them out. These not only help with a cancer diagnosis but can also be used to determine the type of cancer, how advanced it is and the best form of treatment to use against it.

Robotic surgery allows precision operations to be performed

The future of cancer treatment

The more we learn about cancer, the better we are able to target its weaknesses

In the UK, overall cancer survival is now at 50 per cent, and ten-year survival for testicular cancer has reached an impressive 98 per cent. But there's still a way to go. There are hundreds of different types of cancer, and even patients with the same cancer type have subtle differences in their tumours that change their response to treatment. Cancers can become resistant to chemotherapy and radiotherapy, and many treatments also harm healthy cells, causing side-effects that limit their use.

Until recently, most cancer treatments have focused on one thing: cell division. Both radiotherapy and chemotherapy hit rapidly dividing cells, damaging their DNA as they try to replicate, causing them to die. But cancer has lots of other weaknesses and scientists are attacking from all angles, using the latest tech to reveal their genetic and molecular differences.

One tactic is to cut cancer's fuel lines. As tumours grow and cells pile on top of one another, oxygen levels drop and the cancer cells encourage new blood vessel cells to break down tissue and migrate in. Blocking this process could stop tumour growth in its tracks.

Another option is to use the immune system, helping our own cells to see cancer cells and destroy them. Techniques being trialled include using molecules to block the interaction between cancer cells and immune cells, preventing the tumour from switching the immune system off, and genetically engineering immune cells to supercharge their ability to seek and destroy cancer cells.

Immune molecules called antibodies are also being transformed into highly targeted cancer treatments that should leave healthy cells unharmed. They can be made to stick specifically to a single molecule, blocking the chemical signals that tumours need to survive or attaching directly to the cancer cells. They can even be linked to chemotherapy or radiotherapy molecules, delivering a double hit of toxin and immune attack.

Researchers are also working on genetically modifying viruses to infect and kill cancer cells, delivering drugs into cancer cells using nanoparticles and designing small molecules to interfere with the crucial molecular machinery that cancer cells use to survive.

It's very unlikely that there will ever be a single cancer cure, but the more we learn, the more targeted treatments will become, killing cancer cells more effectively and leaving healthy cells unharmed.

Targeting cancer's weaknesses

Modern techniques are zeroing in on the molecules and genetics that make cancer cells vulnerable

Molecular tags

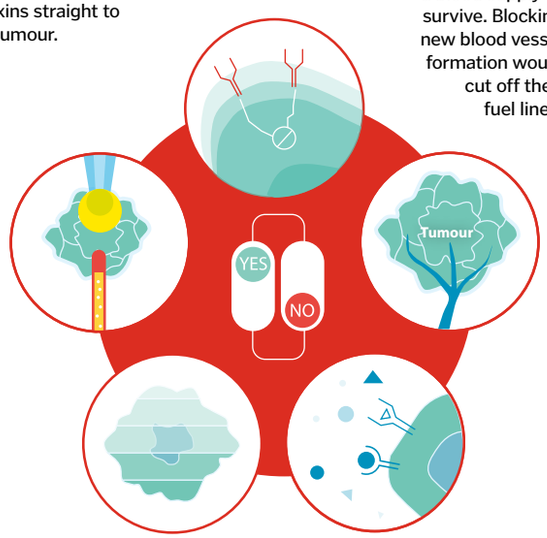
Cancer cell molecules look different. Targeting these could deliver toxins straight to a tumour.

Growth signals

Cancer cells receive signals that tell them to keep growing. Blocking these could halt the process.

Blood supply

Cancer cells need a blood supply to survive. Blocking new blood vessel formation would cut off their fuel lines.



Trawling cancer genetics

Cancers have distinctive mistakes in their genetic code that could reveal weaknesses.

Pathology

Cancer cells can be tested for the presence of molecules that single them out as defective.

Custom treatment

Individual patients could be matched to the treatments most likely to work for their unique tumour.

Self-destruction

Cancer cells don't die even though they are faulty. Targeted therapies could switch self-destruct systems on.

Hormones

Some cancer cells are driven by hormones. Stopping their production could slow growth.

Customising cancer treatment

The Human Genome Project unravelled the human genetic code in 2003. This epic sequencing mission detailed every single letter of our DNA, revealing for the first time the complete recipe book for a human body. Cancer cells read from the same recipe book as healthy cells, just with words blotted out, pages stuck together and sentences scrambled. By understanding how the recipe book is supposed to be put together, scientists are now better able to identify why and how cancer cells have got it so badly wrong.

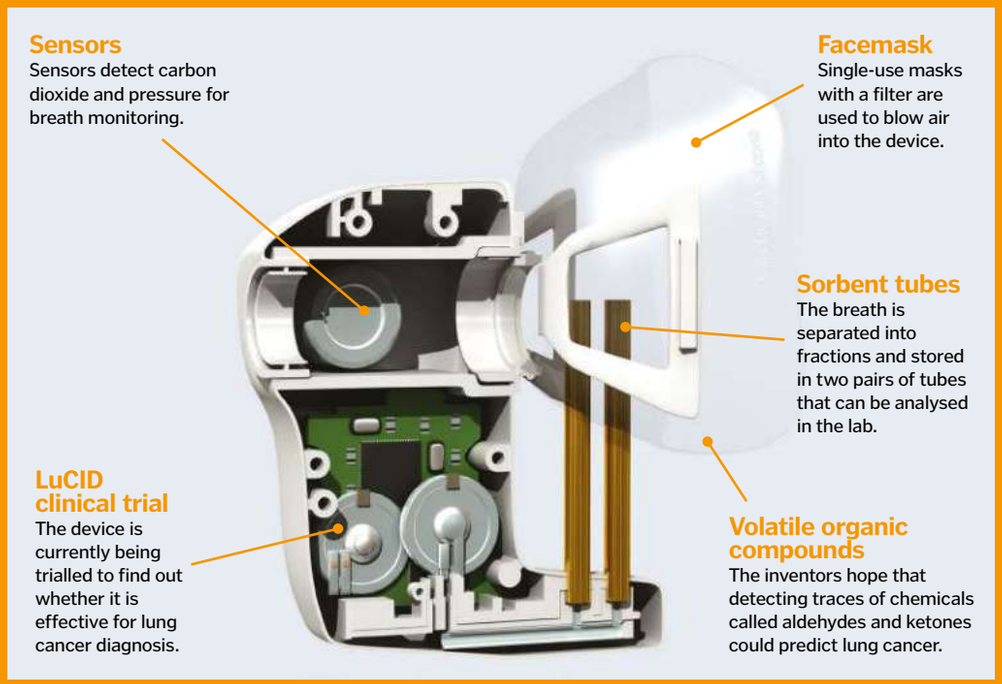
Every person is slightly different and their cancer cells start with a slightly different set of instructions, and as the disease progresses, different tumours adapt in different ways. Two women might both have breast cancer, but although there are patterns of similarity, the genetics inside their cancer cells won't be exactly the same, so they don't always respond in the same way to treatment. In the future, people will be tested to reveal the targeted treatments that will work best for them.

Catching cancer early

The sooner cancer is detected, the easier it is to treat. There are already three screening programmes in operation in the UK to detect bowel cancer, breast cancer and cervical cancer, but in the future things could become a whole lot simpler. Research into 'biomarkers' is searching for molecular signals that could reveal cancer in a simple blood, urine or even breath test.

Biomarkers are molecular signatures unique to different types of cells. Cancer cells differ from normal cells in ways that can already be detected using biopsies of tumour tissue, but researchers think that these differences might also make their way into body fluids, allowing them to be picked up with a simple test. Biomarkers might be able to reveal clues about the best treatment to use, whether the tumour is becoming resistant to current drugs and whether cancer has returned.

"One tactic is to cut cancer's fuel lines"



Sensors
Sensors detect carbon dioxide and pressure for breath monitoring.

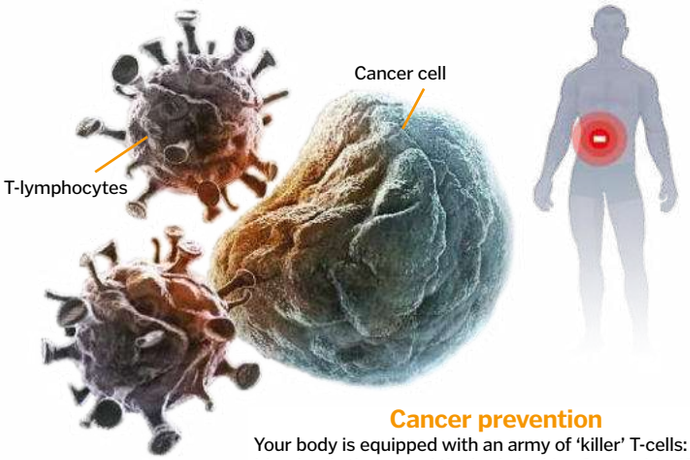
Facemask
Single-use masks with a filter are used to blow air into the device.

Sorbent tubes
The breath is separated into fractions and stored in two pairs of tubes that can be analysed in the lab.

LuCID clinical trial
The device is currently being trialled to find out whether it is effective for lung cancer diagnosis.

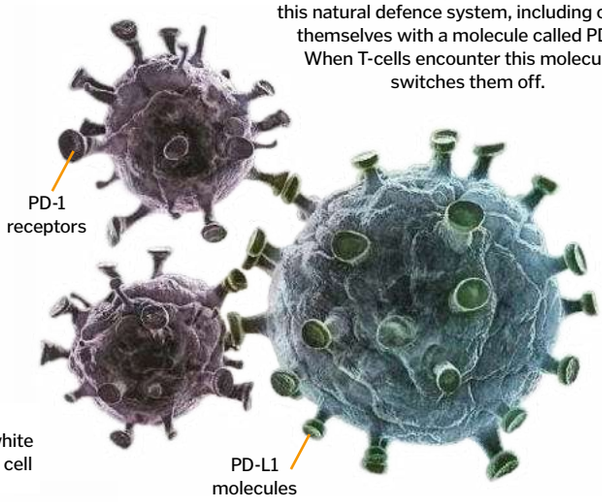
Volatile organic compounds
The inventors hope that detecting traces of chemicals called aldehydes and ketones could predict lung cancer.

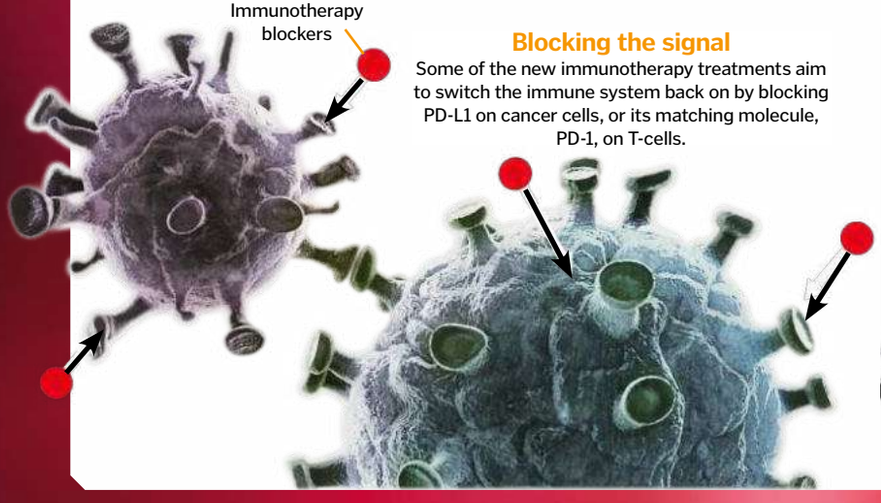
Strengthening your immune army



Cancer prevention
Your body is equipped with an army of 'killer' T-cells: white blood cells that patrol the body looking for trouble. If a cell starts to go wrong, these cells come in and kill it.

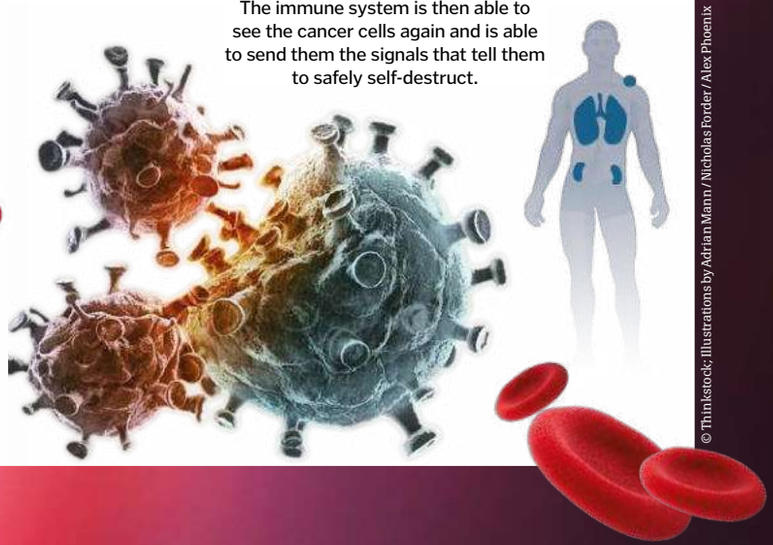
Subterfuge
Cancer cells develop different ways to evade this natural defence system, including coating themselves with a molecule called PD-L1. When T-cells encounter this molecule it switches them off.





Blocking the signal
Some of the new immunotherapy treatments aim to switch the immune system back on by blocking PD-L1 on cancer cells, or its matching molecule, PD-1, on T-cells.

Killing cancer
The immune system is then able to see the cancer cells again and is able to send them the signals that tell them to safely self-destruct.



Expert opinion

How It Works spoke to an immunologist and a research nurse about the future of cancer treatment

The immunologist

***Dr Edd James** is an associate professor in cancer immunology at the University of Southampton, one of the country's leading centres for immunotherapy research*

Could you tell us a bit about your research? What are you trying to find out?
The immune system, in particular the 'infantry' known as killer T-cells, are able to detect cancer cells through examining small protein fragments presented on larger proteins called MHC at the surface of cells. Almost all cells have these MHC molecules and they act as a way to understand what is going on in the cell at that moment. Despite these molecules, cancer cells are able to 'hide in plain sight' from the killer T-cells. We are investigating how they do this and how to either reverse this process or re-educate the killer T-cells to be able to 'see' the cancer cells through changing what the MHC molecules show them.

Why can't the immune system just kill cancer cells on its own?
In many instances, the immune system does kill cancer cells at an early stage of development without us knowing about it. However, cancer cells 'evolve' to hide themselves to prevent the immune system from finding and attacking them. In addition, the cancer cells are able to promote an environment that suppresses the immune response, thus preventing it from working properly.

How does immunotherapy help?
Immunotherapy works in many ways, but there are two main methods by which it can help. The first is to target molecules that the cancer cells have on the cell surface using proteins called antibodies. These are specific for particular molecules and once bound to the target molecules serve to highlight the targeted cancer cells to the immune system. This allows them to be identified, attacked and destroyed.

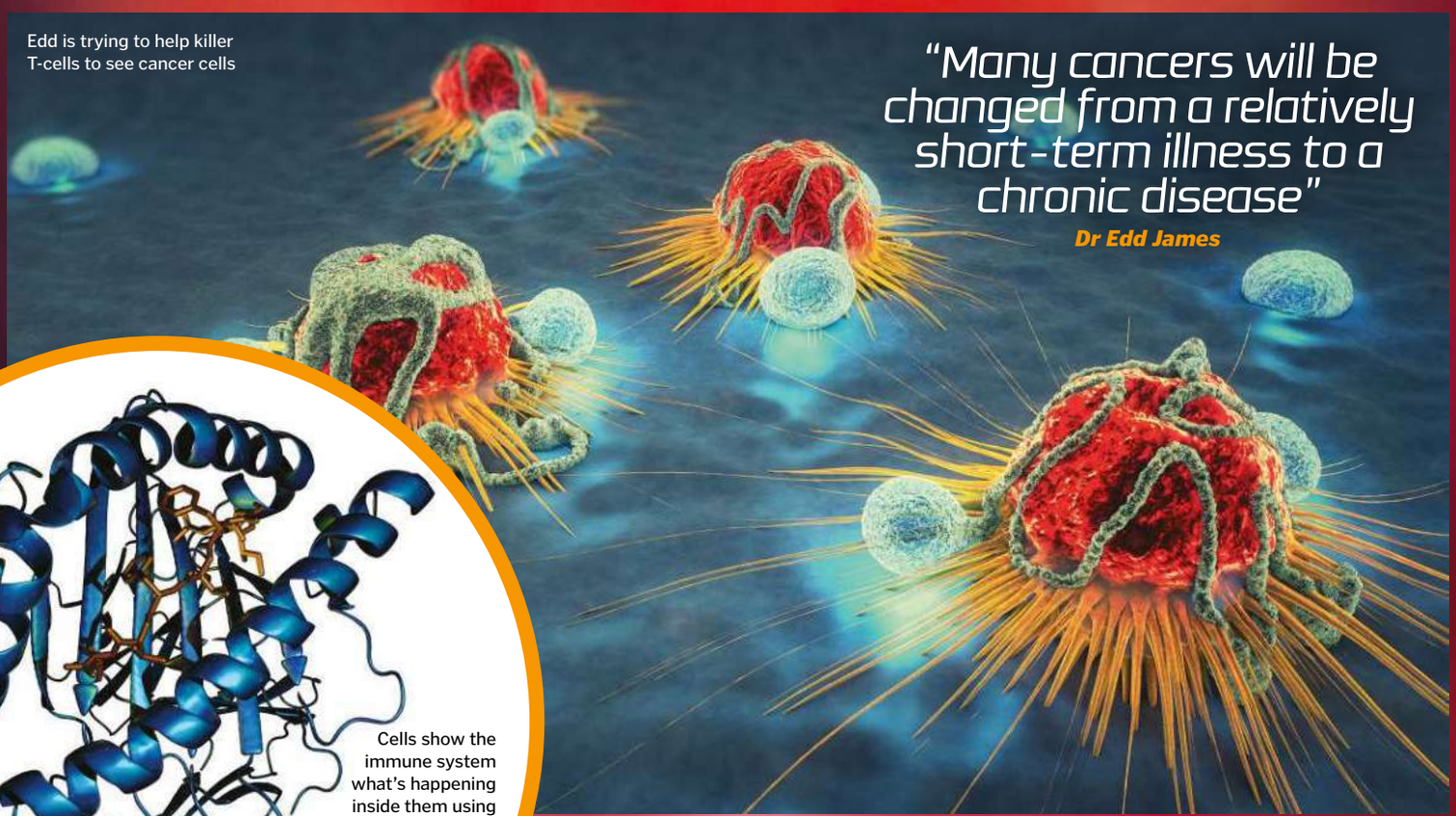
The second method is to target the killer T-cells themselves. Cancer cells are able to put the brakes on the killer T-cells to prevent them working properly. This occurs because the cancer cells deliver a negative, inhibitory signal to the killer T-cells through interaction. These signals are produced through a number of different molecules that can be blocked using antibodies. Blocking these interactions prevents the negative signals and allows the killer T-cells to work normally and kill the cancer cells.

What needs to be done next to make immunotherapy better?
Currently the therapies that are used are relatively blunt tools and aren't effective in many people. We need to understand how the cancer blocks the immune system in greater detail. This will give us a better appreciation of the processes involved in allowing cancer cells to evade the immune system and also allow us to identify new molecules to target.

There are many new investigations looking to combine current immunotherapies to improve their success. In trials these are working much better. However, a major downside of many of these combinations is an increase in side- effects that needs to be addressed.

Do you think we will ever cure cancer?
There is likely to be an effective cure for a number of cancers in the future. Our greater understanding of the molecular aspects of a cancer, and how to utilise the immune system more effectively to kill the cancer, will greatly increase possible treatments and improve their efficacy. This will allow a much more personalised approach to treatment based on the molecular characteristics of the cancer.

These advances will mean that many cancers will be changed from a relatively short-term illness to a chronic disease, where patients are treated as and when cancer arises. This will increase cancer-free survival, effectively enabling many people to live a normal lifespan.



Edd is trying to help killer T-cells to see cancer cells

"Many cancers will be changed from a relatively short-term illness to a chronic disease"
Dr Edd James

Cells show the immune system what's happening inside them using MHC molecules

The research nurse

***Jac Samuel** is a CRUK senior research nurse. She leads a team of research nurses delivering clinical trials testing brand new cancer treatments for the first time*

Could you explain a bit about what research nursing is?

Research nursing is a really interesting career pathway, which most nurses when they qualify don't even consider. You think you're going to work on a ward, and you obviously go into nursing because you want to look after people and help them. Research nursing is interesting because you're working with new treatments that are not licensed.

It's a process of gathering data, which is then analysed to see whether or not this new treatment is comparably better than what we've currently got. It might be that it works better, or it might be that it doesn't work any better but it doesn't have such bad side-effects. Or maybe, instead of giving it via somebody's vein, they might be able to take it in the form of a tablet.

As a research nurse you're delivering those treatments to patients. We don't know how well it works, so we're conducting an investigation. What we're aiming for is really good quality data that can be analysed to prove how well something is working.

Why do treatments have to go through trials?

You can't just give something from a lab because you don't know how it works. Even if it's worked in an animal model, you don't know how it's going to work in a human. Everything has to be tested to make sure it's safe. Otherwise you could have some company saying, 'Hey, we think this really works and it's a cure, and we're going to charge you £50,000 for it' but there would be no evidence for that.

The whole point of research is that it's evidence-based. The laboratories will create the treatment, and they will test it in a cell line and in an animal model, but it's very different to how it might work in a human.

What changes have you seen in cancer treatment?

I've been nursing for a long time now, but even in the last five years actually it has really changed. Scientists have so much more understanding now of the intricacies of cells. Before, there used to be a blanket term for several different sorts of cancer. It's so much more nuanced now, and I think this is only the tip of the iceberg.

There have been certain drugs that have turned it around for patients. Five or ten years ago, you knew with their diagnosis that their prognosis was not great, and yet now you're seeing patients with exactly the same type of disease out of treatment and going strong.

Do you think that there will ever be a cure for cancer?

I think it's really difficult to say that there is going to be one single cure for cancer. The trouble is cancer is such an umbrella term. You've got so many different sorts of cells in your body, and cancer can affect different types of cells in different ways.

I think that as we've seen such a big change in survival rates in the last ten or 15 years, in the next ten or 15 years you're going to see big breakthroughs that are going to make huge differences. We still don't have a cure for cancer, but more people are surviving cancer and their quality of life is better with their treatment, and I think that will continue.

Information and support

For more information about cancer from the NHS visit **www.nhs.uk/Conditions/Cancer/Pages/Introduction.aspx**

If you have questions about cancer, you can contact Cancer Research UK's nurses helpline on 0808 800 4040 Monday to Friday 9am to 5pm.

Need to talk? You can contact Macmillan Cancer Support on 0808 808 00 00 Monday to Friday 9am to 8pm.

If you want to find out more about cancer treatments, Cancer Research UK and FutureLearn have a free online course at **www.futurelearn.com/courses/targeted-cancer-treatments**

Jac's team of research nurses deliver experimental drugs in clinical trials

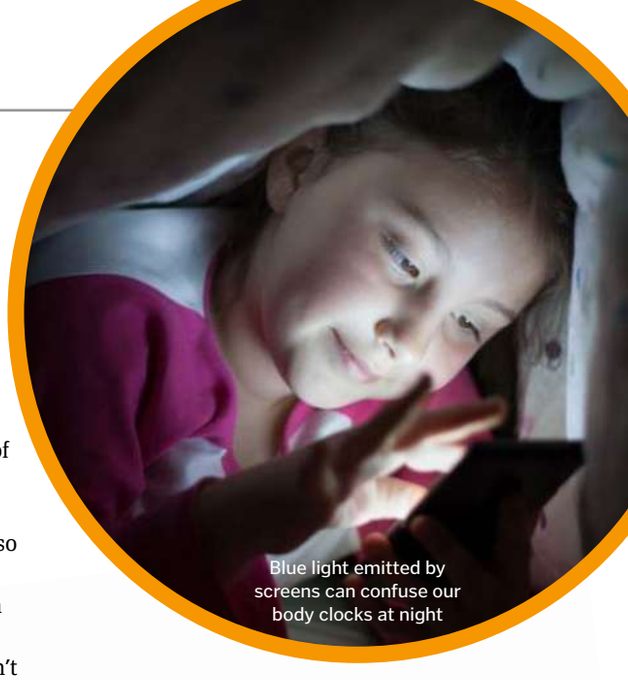
Your biological clock

How biochemical processes keeps you in sync

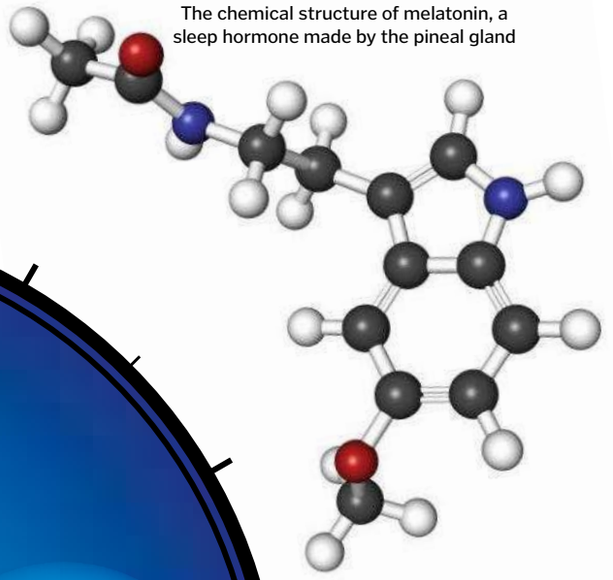
Our bodies run on an in-built 24-hour clock embedded in a part of the brain called the suprachiasmatic nucleus (SCN). Its 20,000 nerve cells sit in the middle of the brain above the back of the eyes and on top of a structure called the hypothalamus. These are the body's master timekeepers, setting the rhythm for sleeping, waking, eating, and hormone release.

Even in a test tube, cells from the SCN keep time. They are stuffed with molecules called transcription factors, which change the production levels of other molecules on a 24-hour cycle. The master regulators are known as BMAL and CLOCK. Together, these two molecules activate the production of molecules called periods and cryptochromes. As levels of periods and cryptochromes rise, they feed back to BMAL and CLOCK, switching production off again. This causes the amount of these molecules to go up and down in cycles, forming the basis for a precise timekeeper.

Like any clock, the SCN can run fast or slow, so the time is reset, or entrained, every day by daylight. This is done by light-sensitive cells in the back of the eye known as intrinsically photosensitive retinal ganglion cells. They don't produce images when they detect light: instead they send signals to the SCN via a bundle of nerve tissue called the retinohypothalamic tract, syncing the master clock, which in turn messages the rest of the body about the time.



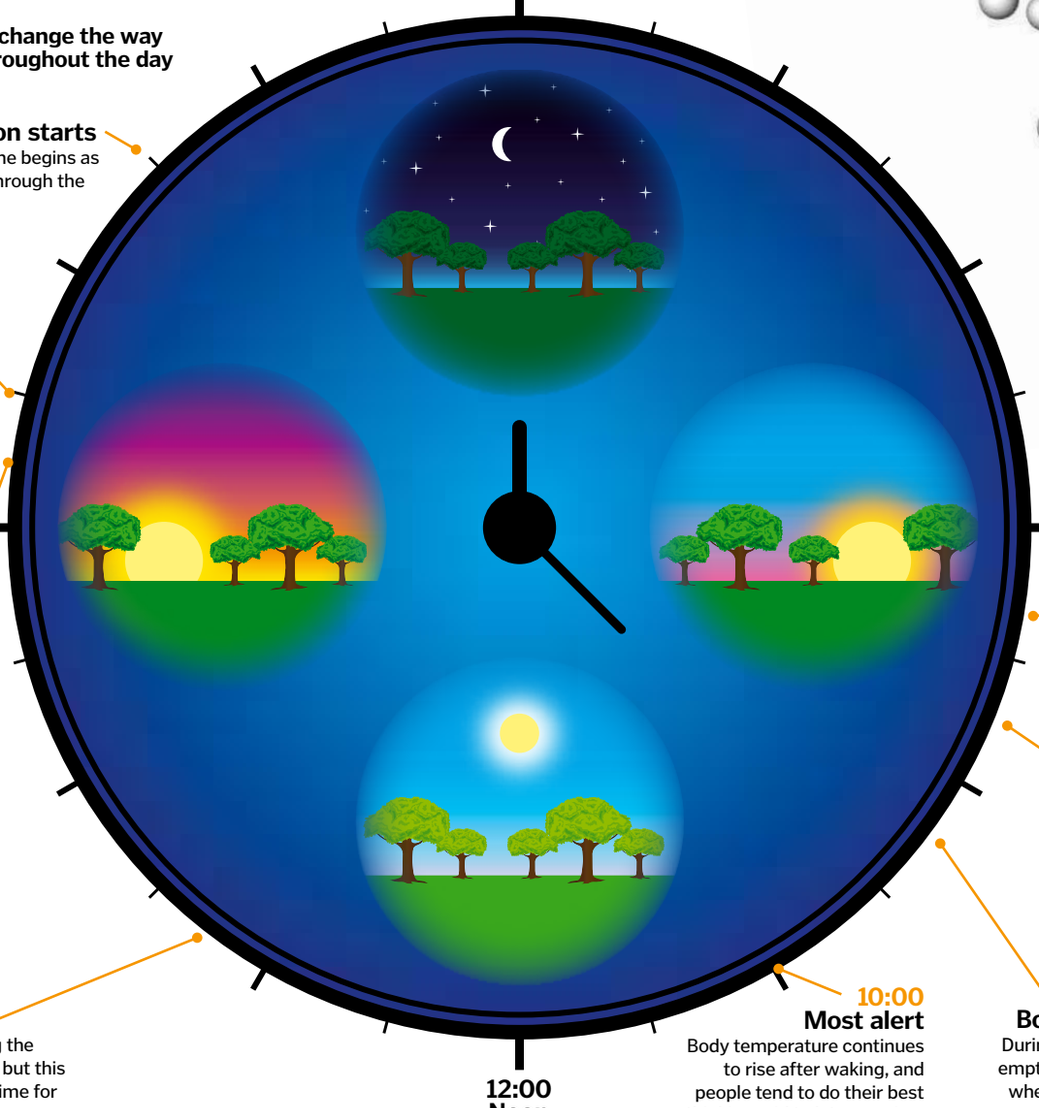
Blue light emitted by screens can confuse our body clocks at night



The chemical structure of melatonin, a sleep hormone made by the pineal gland

Your body around the clock

Internal timekeepers change the way our bodies behave throughout the day



12:00 Midnight

21:00 Melatonin production starts
Release of the sleep hormone begins as darkness falls, continuing through the night until sunrise.

19:00 Highest temperature
Fluctuations in temperature set by the SCN help to keep the rest of the clock in sync. By the evening, body temperature is at its highest.

6:00 PM

18:30 Highest blood pressure
Blood pressure follows the so-called 'dipper' pattern, rising during the day and dropping again at night.

14:30 Most coordinated
Sleepiness can set in during the early afternoon after lunch, but this is also reportedly the best time for coordinated physical activity.

12:00 Noon

10:00 Most alert
Body temperature continues to rise after waking, and people tend to do their best thinking mid to late morning.

8:30 Bowel movement
During the night, stomach emptying slows down, but when you wake up bowel movement restarts.

6:00 AM

6:45 Blood pressure up
Morning light enters the eye, sending a signal to the SCN to reset the circadian clock. Temperature and blood pressure soon rise.

7:30 Melatonin production stops
The SCN sends signals to the pineal gland telling it to stop producing the sleep hormone, melatonin.

Batteries

Without them our modern lives would be very different indeed

Powering our phones, laptops, cars and more, batteries are modern technological marvels. Their invention dates back to 1800, when Italian scientist Alessandro Volta first came up with the idea of creating a cell that could generate power.

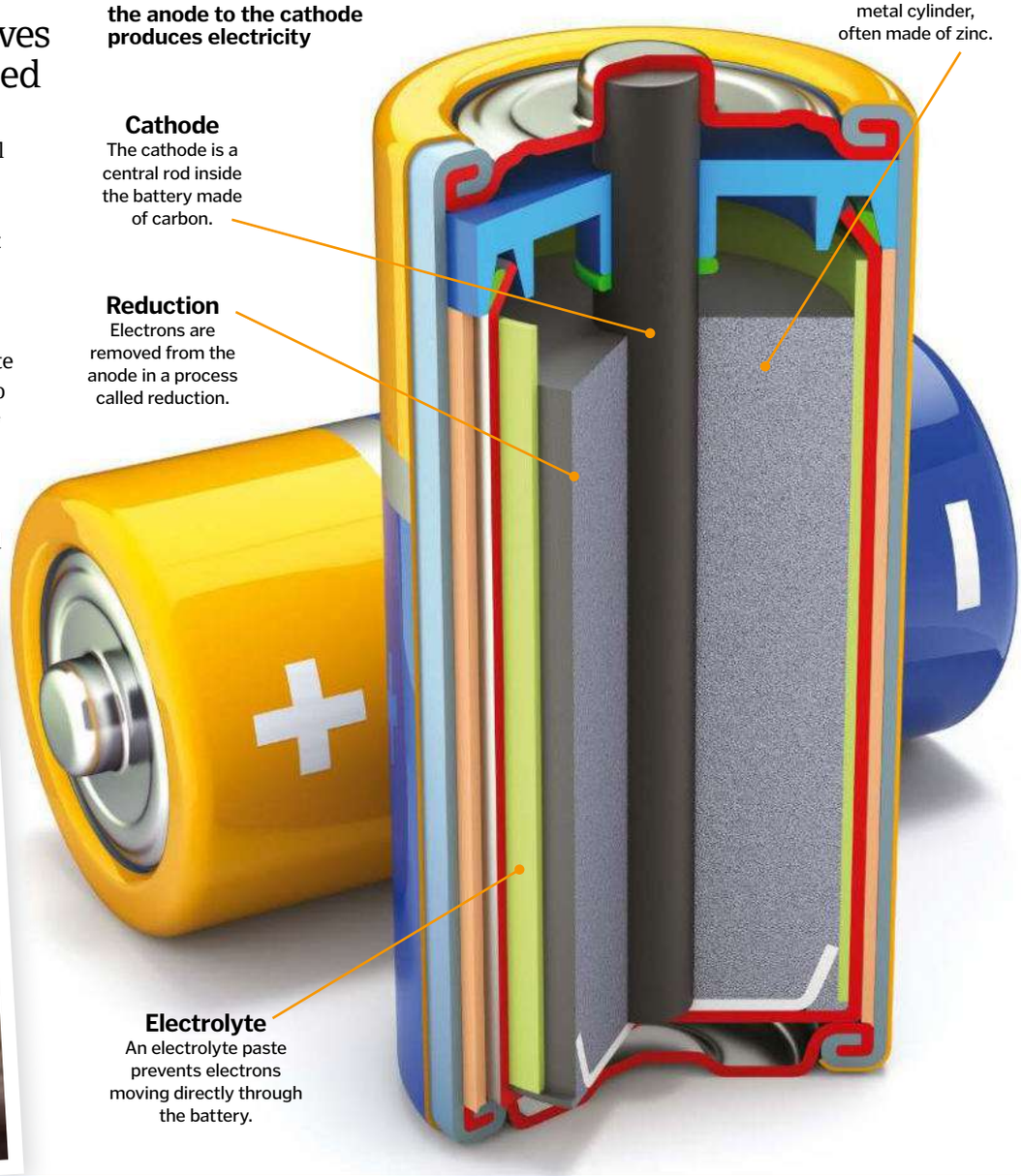
At its heart, a battery involves ferrying electrons between an anode and a cathode. Using an electrolyte – essentially chemical waste – these electrons can't go through the battery, so instead they go around the outside. As they flow around they complete a circuit, and when plugged into a device this flow of electrons provides power.

Different batteries use different reactions and chemicals, such as zinc and alkaline. At their core, though, they all work in the same way.

Batteries must be specially recycled if you want to get rid of them safely

Inside a dry cell

The flow of electrons from the anode to the cathode produces electricity



Anode
The anode in a dry cell battery is a metal cylinder, often made of zinc.

Cathode
The cathode is a central rod inside the battery made of carbon.

Reduction
Electrons are removed from the anode in a process called reduction.

Electrolyte
An electrolyte paste prevents electrons moving directly through the battery.

The Xi particle

How this discovery could open up a new realm of physics

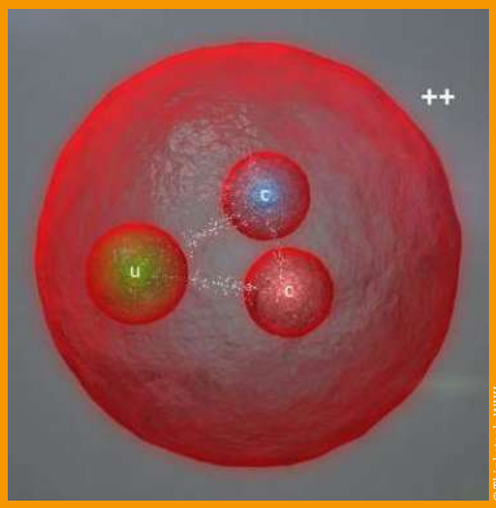
In July 2017, CERN announced the first observation of the Xi particle. This particle had been theorised before but it took the Large Hadron Collider atom smasher to find it.

All particles are made of various subatomic particles known as quarks. This particular particle, technically known as Xi-c-c-plus-plus (Xi_{cc}^{++}), is made up of two charm quarks and one up quark. It is a baryon, the family of particles that includes things like protons and neutrons. All baryons are made of three quarks.

The Xi particle is interesting because it is four-times heavier than a proton. This is because of its two charm quarks, which are 'heavy' quarks, making this the first such particle that has ever been found.

The Xi particle is a bit different from other baryons, where all three quarks dance around each other. In the Xi particle, its two heavier quarks behave like giant stars orbiting each other and the lighter up quark (the lightest of all quarks) orbits around these two.

It's thought that there could be other double-heavy baryons out there awaiting discovery, so the Xi particle has opened the door to some more exotic physics in the future.



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Comprising two charm quarks and one up quark, the Xi particle could help scientists test the laws of the universe

Are viruses alive?

Are these biological hitchhikers a lifeform?

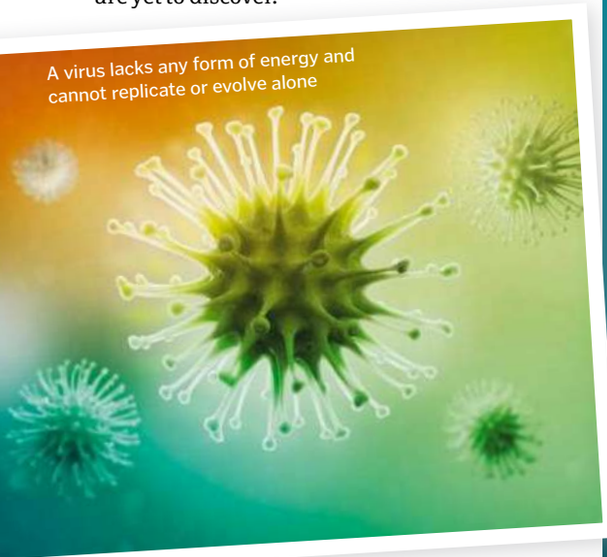
The first virus to be discovered was the Tobacco mosaic virus in 1892 and the controversy surrounding their classification as living or not living has been debated ever since.

The debate centres around the fact that viruses cannot survive without a host and they are unable to carry out even the most simple of biological processes alone. However, with a host they are able to function and reproduce like any other life form. This is because a virus is essentially an isolated free roaming string of DNA without its own cell or metabolic processes, so it has no cell of its own or the enzymes that are needed for chemical reactions such as the steps required to gain energy.

The string of nucleic acid is generally only between three to 400 genes long, and to survive it needs a host to produce and carry out the chemical reactions required to live.

Once a virus reaches a cell it is able to get inside and hitch a ride with the DNA of the host. It then combines with the DNA of the host and use it to sustain itself. Viruses can reproduce here using the cells' code for building new copies. It will then burst out of the cell when it becomes packed with replicated viruses.

For now, most scientists support the theory that viruses cannot constitute as being alive. However, it is agreed that if they are classified as life then they are the simplest form of it that we are yet to discover.



A virus lacks any form of energy and cannot replicate or evolve alone

The diving reflex

Your body's reaction to prevent you from drowning

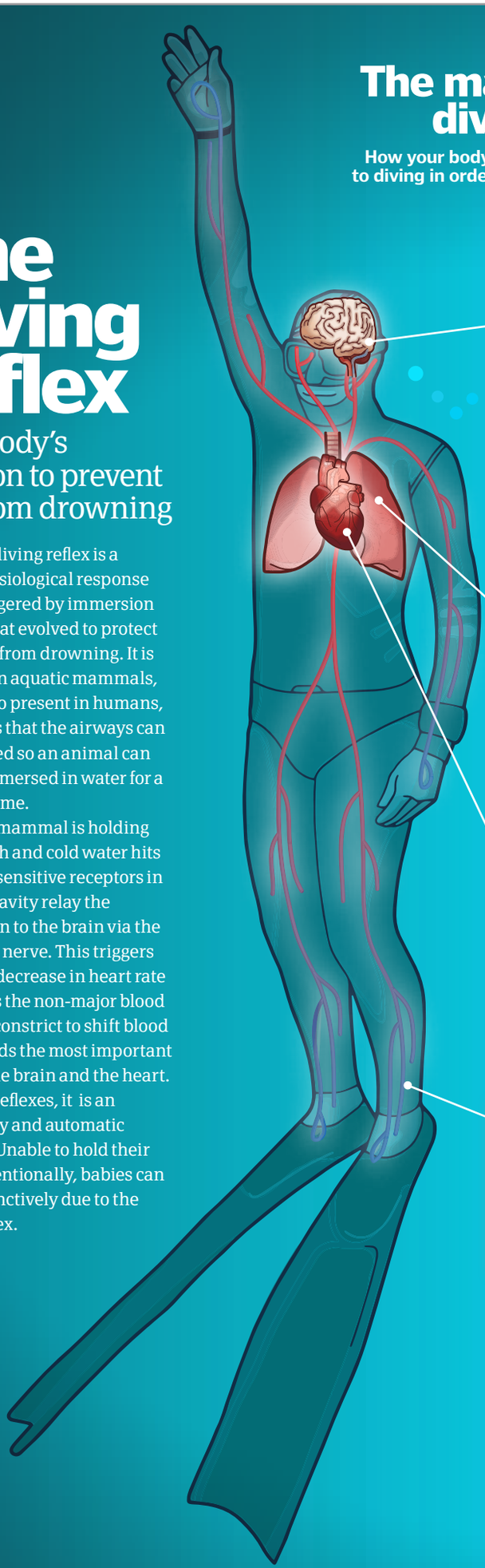
The diving reflex is a physiological response triggered by immersion in water that evolved to protect mammals from drowning. It is strongest in aquatic mammals, but it is also present in humans, and means that the airways can be protected so an animal can survive immersed in water for a period of time.

When a mammal is holding their breath and cold water hits their face, sensitive receptors in the nasal cavity relay the information to the brain via the trigeminal nerve. This triggers an abrupt decrease in heart rate and causes the non-major blood vessels to constrict to shift blood flow towards the most important organs – the brain and the heart.

Like all reflexes, it is an involuntary and automatic response. Unable to hold their breath intentionally, babies can do so instinctively due to the diving reflex.

The mammalian diving reflex

How your body instinctively responds to diving in order to avoid a watery end



Cold water
Facial immersion in cold water, particularly around the eyes and the forehead, are one of the main triggers of the diving reflex.

Breath holding
The effects of the dive reflex help conserve oxygen and prolong the amount of time we need between breaths.

Heart rate slows
Human heart rate slows down to between ten and 25 per cent to reduce the amount of oxygen the body needs.

Blood shifts
Blood shifts as blood vessels close in the outer limbs, forcing blood towards the head and torso to keep the vital organs supplied with oxygen.

How this marvellous vehicle ferried astronauts to and from orbit for 30 years

THE SPACE SHUTTLE

On 12 April, 1981, the Space Shuttle launched into our skies for the first time as the orbiter Columbia lifted off from Cape Canaveral in Florida. This mission, STS-1, was the first in what would be 135 successful missions in 30 years of service. Two terrible tragedies — Challenger in 1986 and Columbia in 2003, both of which lost their entire crews — overshadowed the programme in its later years. But the achievements of the Shuttle were many.

The Space Shuttle was born from a desire to make space more accessible. Following on from the expensive race to the Moon with the Soviet Union, the Shuttle was NASA's attempt to get back on more steady footing. After the US emerged victorious by landing on the Moon in 1969, President Richard Nixon wanted a new direction for NASA. They began to develop the Space Shuttle, a reusable method to reach orbit at what was hoped to be a lower cost.

Originally, NASA had planned the Shuttle to be a fully reusable two-stage vehicle, both piloted on their way to space. Budget cuts, however, led to a still impressive but decidedly clunkier design that did not quite live up to the dream of reusability. The Shuttle launched strapped to a giant tank of fuel, with two side solid rocket boosters (SRBs) attached to give it an extra kick. The orbiter itself was reusable and could land on a runway, but the tank was expendable and the boosters had to be recovered from the sea, where they were damaged by salt.

> *"Thanks to the Space Shuttle we could build the ISS"*

Despite its flaws, the Shuttle was unique. Previously, astronauts had launched to space in cramped capsules. Here was a roomy vehicle that could launch seven people and with them satellites and other equipment to use or release in orbit. Thanks to the Shuttle we were able to launch and service the Hubble Space Telescope, perform countless experiments in orbit, learn more about human spaceflight than ever before and build the International Space Station.

The Space Shuttle made spaceflight routine in an age where it had been anything but. It flew for the last time in July 2011 when Atlantis completed the STS-135 mission. And although it comes in for some deserved criticism, there's no doubt about its huge impact on space travel.

Three decades in orbit

How this pioneering spacecraft helped open up the final frontier

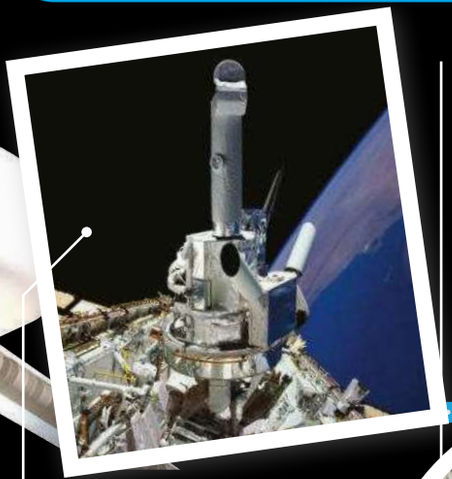
1981

First American female astronaut

Sally Ride became the first American woman to go into space on 18 June, 1983. She flew aboard Space Shuttle Challenger on the STS-7 mission, deploying communications satellites and conducting experiments during six days in orbit. Ride flew once more in 1984 but sadly died from cancer in 2012.

First African-American astronaut in space

Guion Bluford became the first African-American to go into space on Challenger's STS-8 mission on 5 September, 1983. This mission released an Indian communications and weather observation satellite. Bluford flew on three more Shuttle missions before leaving NASA in 1993.



Longest mission

STS-80 was the longest Space Shuttle mission, totalling 17 days, 15 hours and 53 minutes. It was flown by Space Shuttle Columbia from 19 November to 7 December, 1996. The landing should have been two days earlier but bad weather prevented the Shuttle returning to the runway on schedule.

1991

Launching Hubble

Arguably the most famous Shuttle mission, STS-31 on 24 April, 1990, saw the Hubble Space Telescope taken to orbit. It was deployed a day later in a high orbit 612 kilometres above Earth to prevent it being dragged into the atmosphere.

2001

Microgravity research

More than 20 Shuttle missions were dedicated to low-gravity research in a quest to understand the effects of microgravity on biological, chemical and physical systems. This was done aboard a specially designed Spacelab module, which was used to see how cells responded to flying in space, among other experiments.

Fixing Hubble

Four separate servicing missions between 1993 and 2009 kept Hubble working properly. The first replaced its primary mirror, which had been launched with a flaw. No other spacecraft before or after has been capable of such servicing missions.

Inside the Space Shuttle

How the design of this vehicle allowed it to perform groundbreaking science in orbit

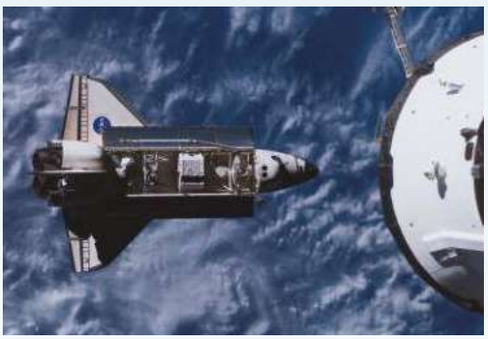
The design of the Space Shuttle incorporated a number of key demands that needed to be met. These included making it highly reliable, able to carry a large variety of cargo and making it as versatile in orbit as possible. Most of these conditions were indeed met, making the large majority of Shuttle flights a success.

One of the Shuttle's key successes was its cargo bay. Using swinging bay doors it was able to accommodate lots of different payloads, from satellites to experiments. The doors were designed to not only be sturdy at launch but also to be opened in space. Crucially, they had to close tightly for re-entry to prevent any hot gases getting inside the vehicle. A zipper-like system ensured the doors would close even if they were distorted by temperature changes or Earth's gravity.

Another key innovation was the use of the Canadarm, a long mechanical arm that was used to deploy satellites and other tasks. On later missions it was used to inspect the Shuttle for damage following the Columbia disaster, when a hole in the Shuttle's left wing caused it to disintegrate on re-entry in February 2003, tragically killing all seven crew members.

One of the greatest innovations, though, was that the entire Shuttle orbiter was designed to return to Earth as a glider. Because the main fuel tank was jettisoned on the way to orbit, the Shuttle did not have access to propellant during the descent even though its own engines were still attached. Using a low glide angle and a long drift time, the Shuttle was able to return from speeds in orbit of 27,800 kilometres per hour to about 400 kilometres per hour when landing.

"The Shuttle was designed to return to Earth as a glider"



Key components

The major parts of the Space Shuttle that made it a success

Main engines
These helped the Shuttle reach orbit when attached to the fuel tank and boosters.

Split rudder
This enabled the Shuttle to turn in the air and also acted as a speed brake.

Payload bay
The large payload bay and its doors allowed cargo to be transported to space.

Delta wings
The two delta wings allowed the Shuttle to glide back to Earth from orbit.

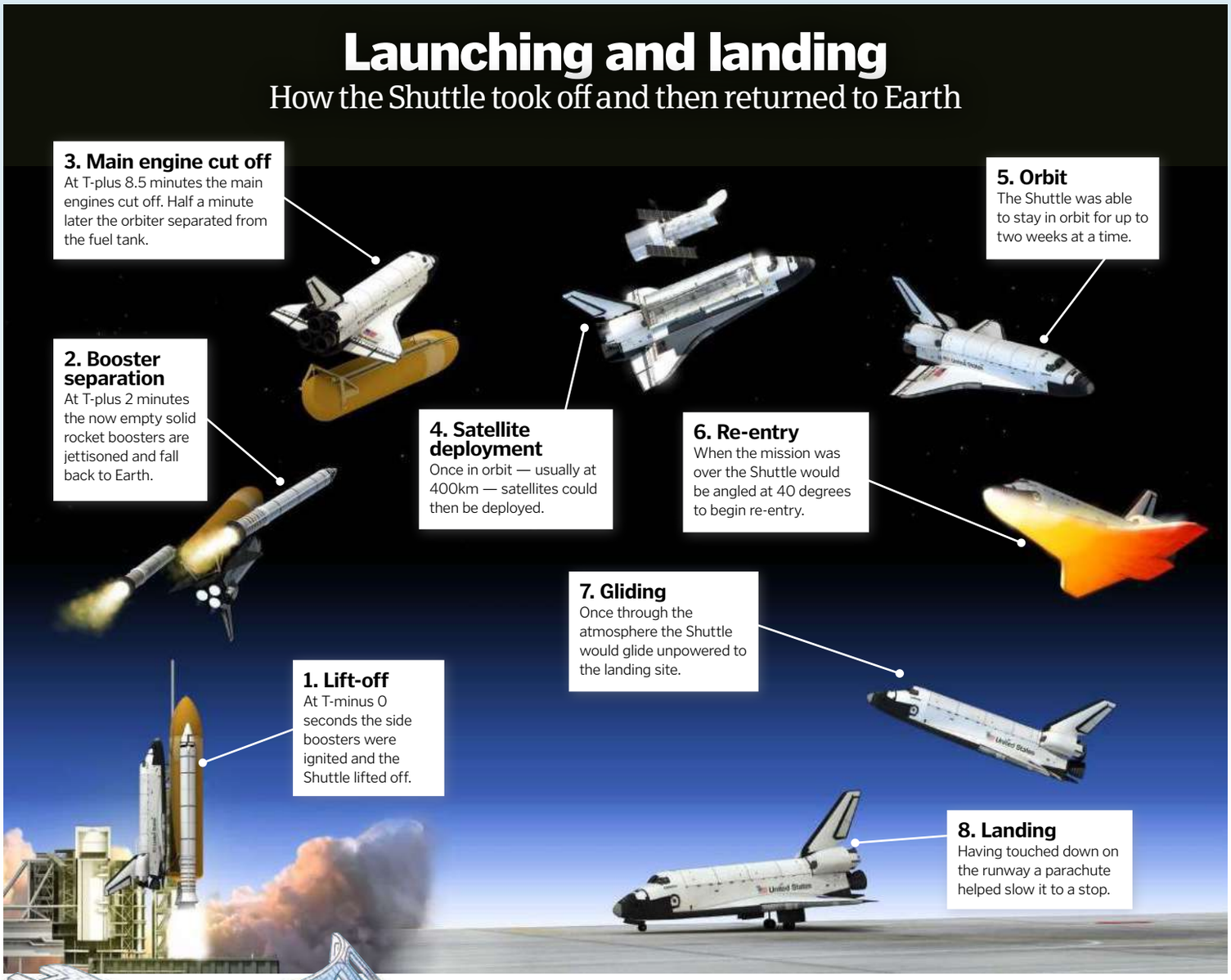
Tyres
The six tyres and landing gears could bear three times the load of a Boeing 747.

Reaction-control system
These thrusters enabled the Shuttle to manoeuvre itself in orbit.

The total cost of the Space Shuttle's 30 years of service was $196 billion (£152.2 billion)

Launching and landing

How the Shuttle took off and then returned to Earth



1. Lift-off
At T-minus 0 seconds the side boosters were ignited and the Shuttle lifted off.

2. Booster separation
At T-plus 2 minutes the now empty solid rocket boosters are jettisoned and fall back to Earth.

3. Main engine cut off
At T-plus 8.5 minutes the main engines cut off. Half a minute later the orbiter separated from the fuel tank.

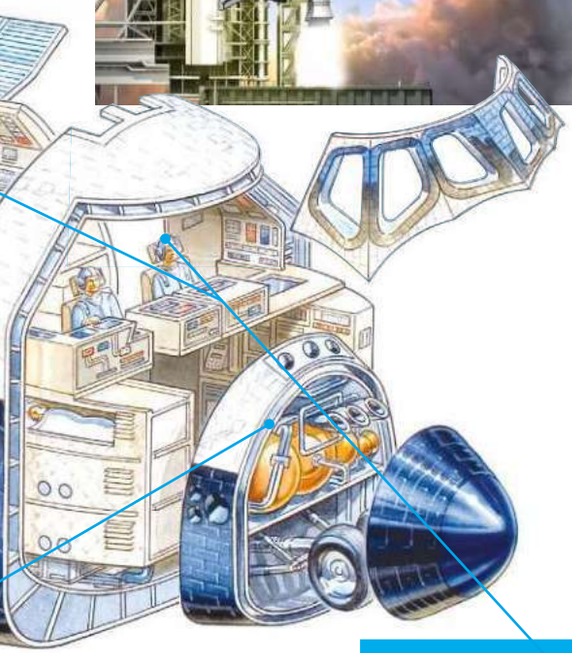
4. Satellite deployment
Once in orbit — usually at 400km — satellites could then be deployed.

5. Orbit
The Shuttle was able to stay in orbit for up to two weeks at a time.

6. Re-entry
When the mission was over the Shuttle would be angled at 40 degrees to begin re-entry.

7. Gliding
Once through the atmosphere the Shuttle would glide unpowered to the landing site.

8. Landing
Having touched down on the runway a parachute helped slow it to a stop.

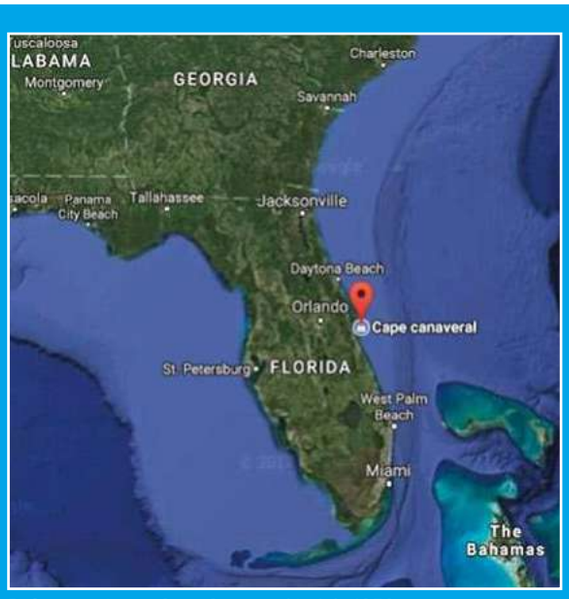


Crew cabin
The Space Shuttle cockpit and crew cabin housed up to seven people on each flight.

Why launch from Florida?

Cape Canaveral in Florida has a number of benefits for rocket launches. For one thing, it's relatively close to the equator, which gives rockets a speed boost from Earth's rotation. The rotation on our planet is fastest near the equator, so the closer you are — provided you launch in the same direction as Earth is rotating — the faster your rocket will go.

That's important for another reason. In order to get this speed boost you need to launch east in the Northern Hemisphere. As many rockets, including the Shuttle, have expendable parts, it's best if you launch over an ocean so that pieces do not fall on the ground. Thus, Florida is ideal as it's on the east coast and also relatively near the equator. Launch pads elsewhere in the world are located in similar positions for the same reasons.



Before moving to Cape Canaveral in July 1950, NASA launched its rockets from New Mexico

Mission summary

The trailblazing missions that made the Shuttle a legend

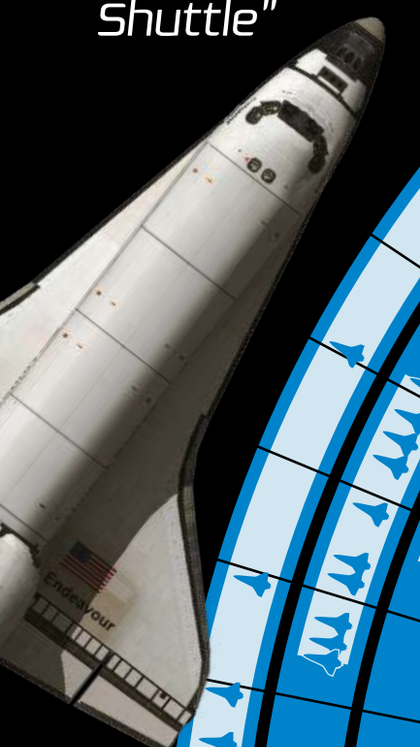
There were 135 Space Shuttle missions that successfully made it to orbit. All of these performed some incredible science. The inaugural launch of Space Shuttle Columbia on 12 April, 1981, was no doubt one of the most important, and it achieved a number of firsts. It was the first time solid rocket boosters (SRBs) were used on a manned vehicle, and it also marked the first time a manned spacecraft had returned on a runway landing.

The launch of the Hubble Space Telescope in 1990 was of course pivotal, but perhaps equally so was the first servicing mission in 1993. This proved the Shuttle's capabilities as a reusable spacecraft that could repair satellites in orbit. STS-93 in 1999 was also important as it launched the Chandra X-ray Observatory, which has helped us study supernovae, nebulae, black holes and more.

Just prior to that in 1995, the STS-71 mission heralded a new era in partnership between the US and Russia when Space Shuttle Atlantis docked with the Mir space station. In 1998, Endeavour carried out the STS-88 mission that began the start of a new collaboration, the construction of the International Space Station (ISS).

The final mission, STS-135, launched on 8 July, 2011, was a sombre one as it brought the programme to a close. Atlantis delivered two major components to the ISS and brought to a close one of the greatest technological achievements of our time.

"The ISS would not have been possible without the Space Shuttle"



ESTIMATED TOTAL DISTANCE TRAVELLED (KM)

872000000

135 Shuttle missions

01. First Shuttle launch
The first Space Shuttle launch was Columbia on 12 April, 1981.

02. Challenger accident
Just 73 seconds after launching, Space Shuttle Challenger exploded on 28 January, 1986.

03. Hubble Space Telescope deployed
Space Shuttle Discovery successfully deployed the Hubble Space Telescope in late April 1990.

04. Mir
29 June, 1995, saw the first Shuttle to dock with Mir and the 100th US manned space flight.

05. Longest mission
19 November, 1996. This was the longest Space Shuttle mission at 17 days, 15 hours, 53 minutes and 18 seconds.

06. ISS construction
The Shuttles took more than 85 per cent of the International Space Station's parts into orbit.

07. Columbia accident
On 1 February, 2003, Space Shuttle Columbia disintegrated as it re-entered Earth's atmosphere.

08. Final launch of Shuttle
Atlantis launched on the final Space Shuttle mission on 8 July, 2011.

Five key stats

238.5mn km

The distance covered by Space Shuttle Discovery, which travelled the furthest of all five Shuttles during its service.

100,000kg

The approximate weight of the Shuttle orbiter upon its re-entry into the Earth's atmosphere.

2mn kg

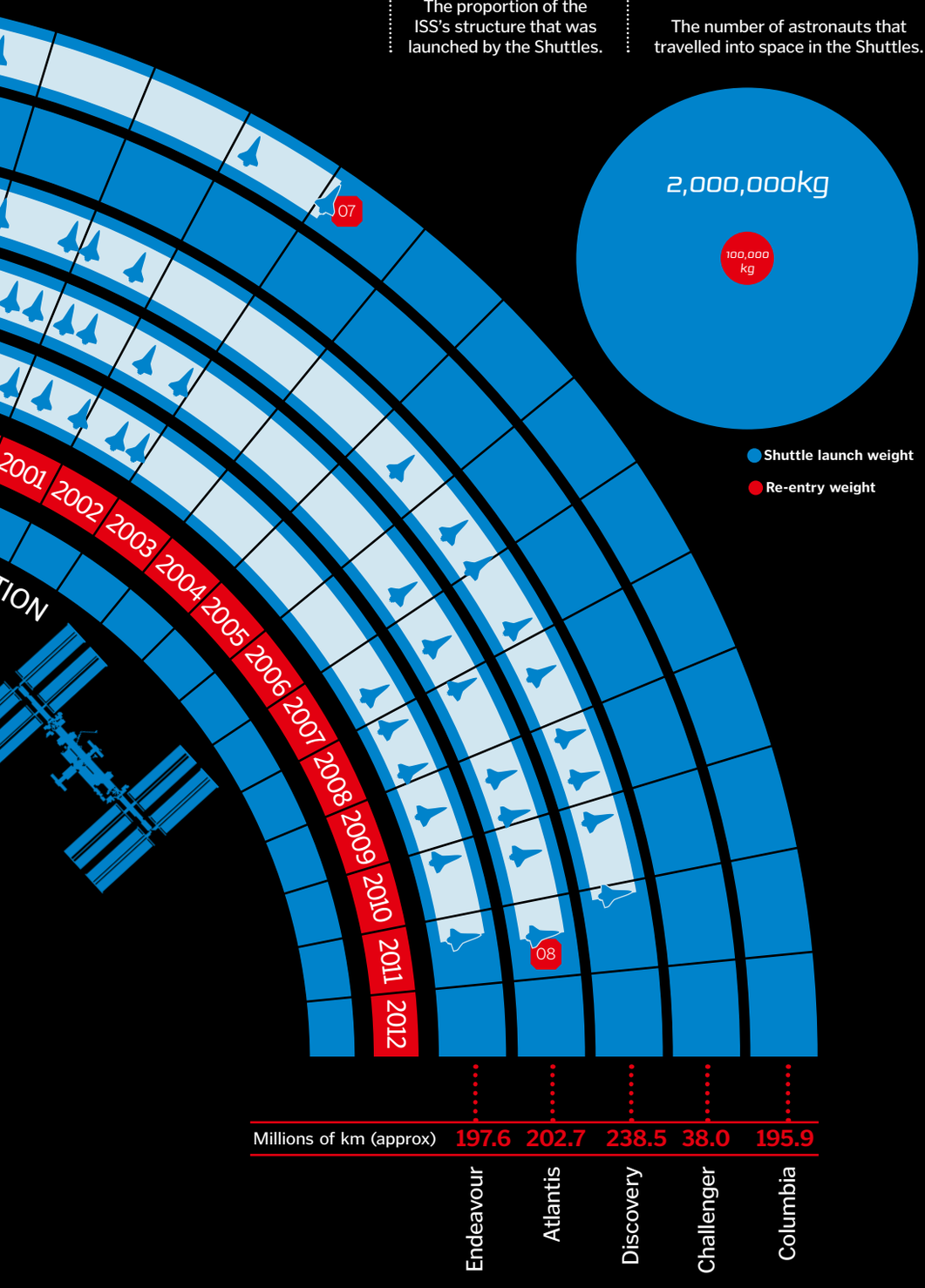
The combined weight of the Shuttle, boosters and tank at launch.

Over 85%

The proportion of the ISS's structure that was launched by the Shuttles.

600

The number of astronauts that travelled into space in the Shuttles.



The Shuttle's lasting legacy

While the Shuttle has now gone, it has left behind a shining legacy of exploration

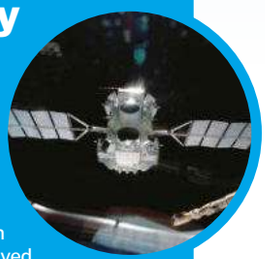
International Space Station

The ISS is one of the greatest human-made constructions of all time. This vast $100 billion (£79.2 billion) station spans the size of a football pitch and has been continuously manned since 2000. It was assembled in space, and its construction arguably would not have been possible without the Space Shuttle. Today, astronauts continue to work on the ISS and conduct groundbreaking research not only into spaceflight but also into areas that improve our lives here on Earth.

Hubble Space Telescope

Since its launch in 1990, the Hubble Space Telescope has made countless discoveries. It has peered into the distant universe and found galaxies stretching back to just 400 million years after the Big Bang. It's taken Deep Field images of the cosmos, revealing a vast number of galaxies, and closer to home it has found water bursting from Jupiter's moon, Europa. Still going strong, who knows what the Hubble will find next?

Chandra X-ray Observatory



Still operational today, the Chandra X-ray Observatory is one of NASA's 'Great Observatories' along with Hubble, the Gamma Ray Observatory and the Spitzer Space Telescope. Launched on Columbia in 1999, it has observed the universe in X-rays to help astronomers see into the centre of a supernova. It has found a galaxy being eaten by another and also observed the X-ray emissions from the supermassive black hole at the centre of our galaxy.

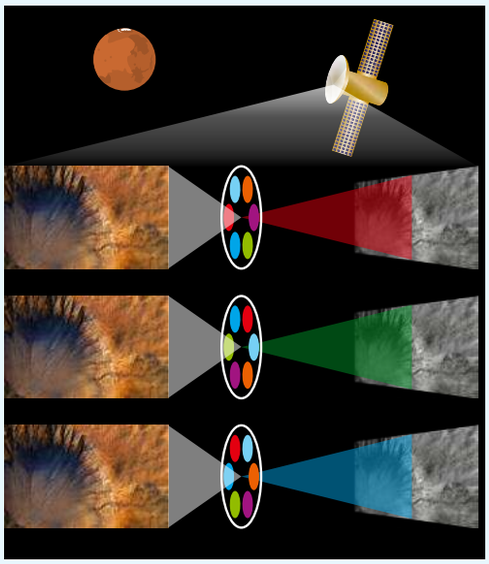
Microgravity research

Thanks to the Shuttle we were able to perform some fascinating microgravity research in orbit that still has impacts today. It proved that cells could grow in microgravity, even with a lack of fluid mixing due to gravity. Experiments also discovered that some immune cells were not as effective while in microgravity, which has implications for long-duration space travel. And it also helped test the limits of how humans can operate in space.

How spacecraft take photos

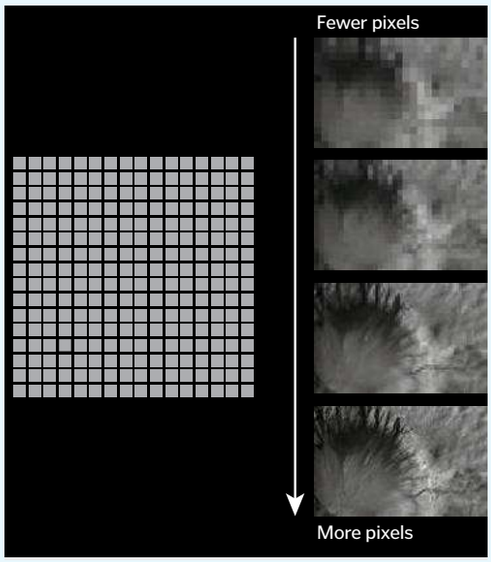
Getting an image back to Earth from a probe can be complicated but it's worth it in the end

And here's Mars, as seen by the Mars Global Surveyor



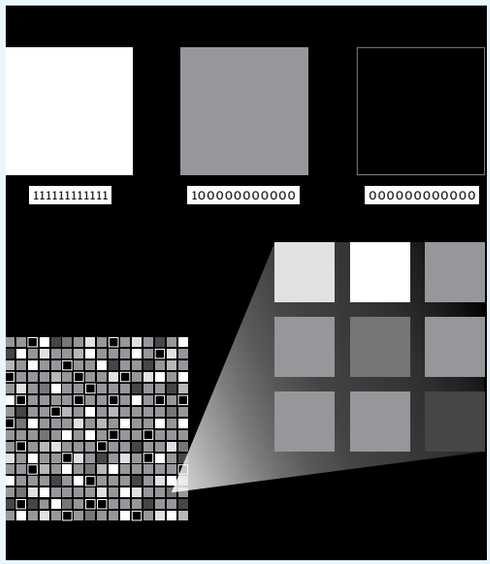
1 Using filters

First, the spacecraft will snap its visible image – such as Mars or Saturn – using a camera with three filters. These are red, green and blue. They'll later be recombined to make the full image.



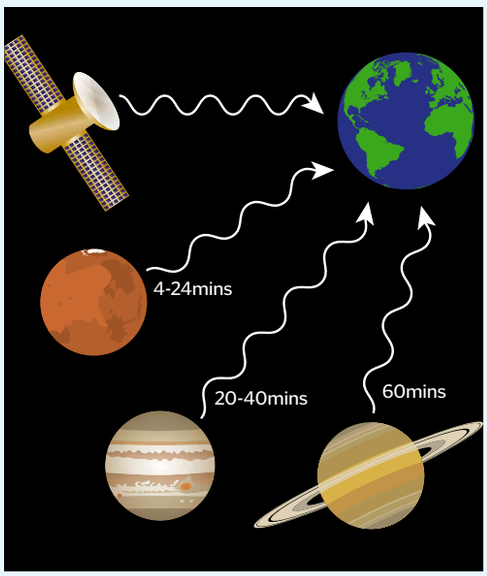
2 CCDs and pixels

Each filter stores the image as pixels on a charge-coupled device (CCD). This circuit converts the pixels of each image into data. The more pixels a camera has, the more detailed the image.



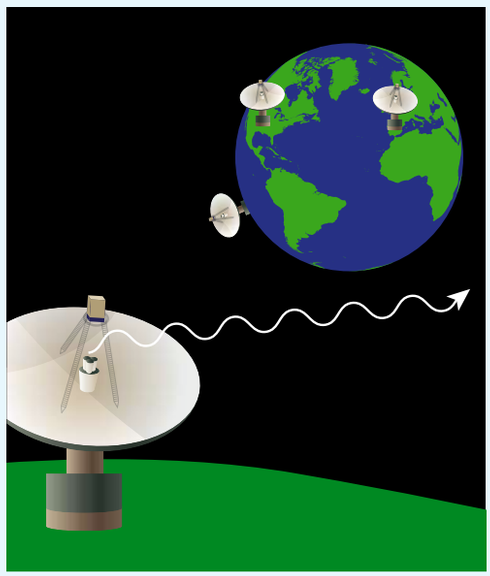
3 Storing the image

The data on each pixel is then stored as a 12-digit binary number on the spacecraft's computer. Using these numbers, a computer on Earth can then piece together what the original image looked like.



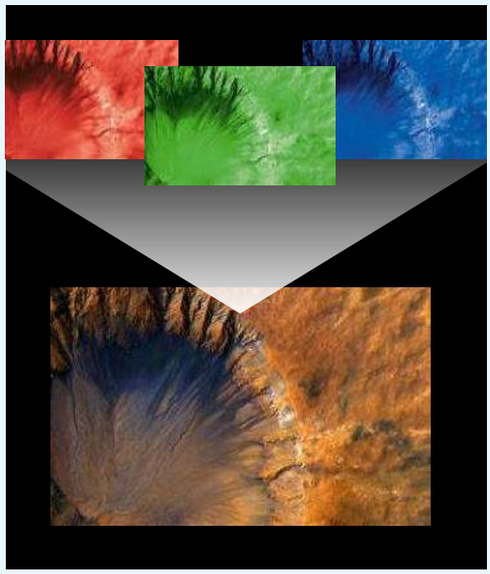
4 Transmitting the data

The spacecraft will then send its data back to Earth in the form of radio waves. The time this will take will vary on the distance. From Saturn, for example, it can take an hour to send data back to Earth



5 Receiving the data

Back on Earth, NASA has three big dishes in the US, Spain and Australia that it uses to collect the data. This is then relayed to other locations so that the image can be stitched together.



6 Recreating the image

The data is then laid out in the order it was recorded. By combining the pixels from the red, green and blue filters, the original image can now be recreated, giving us a fantastic view of another world.

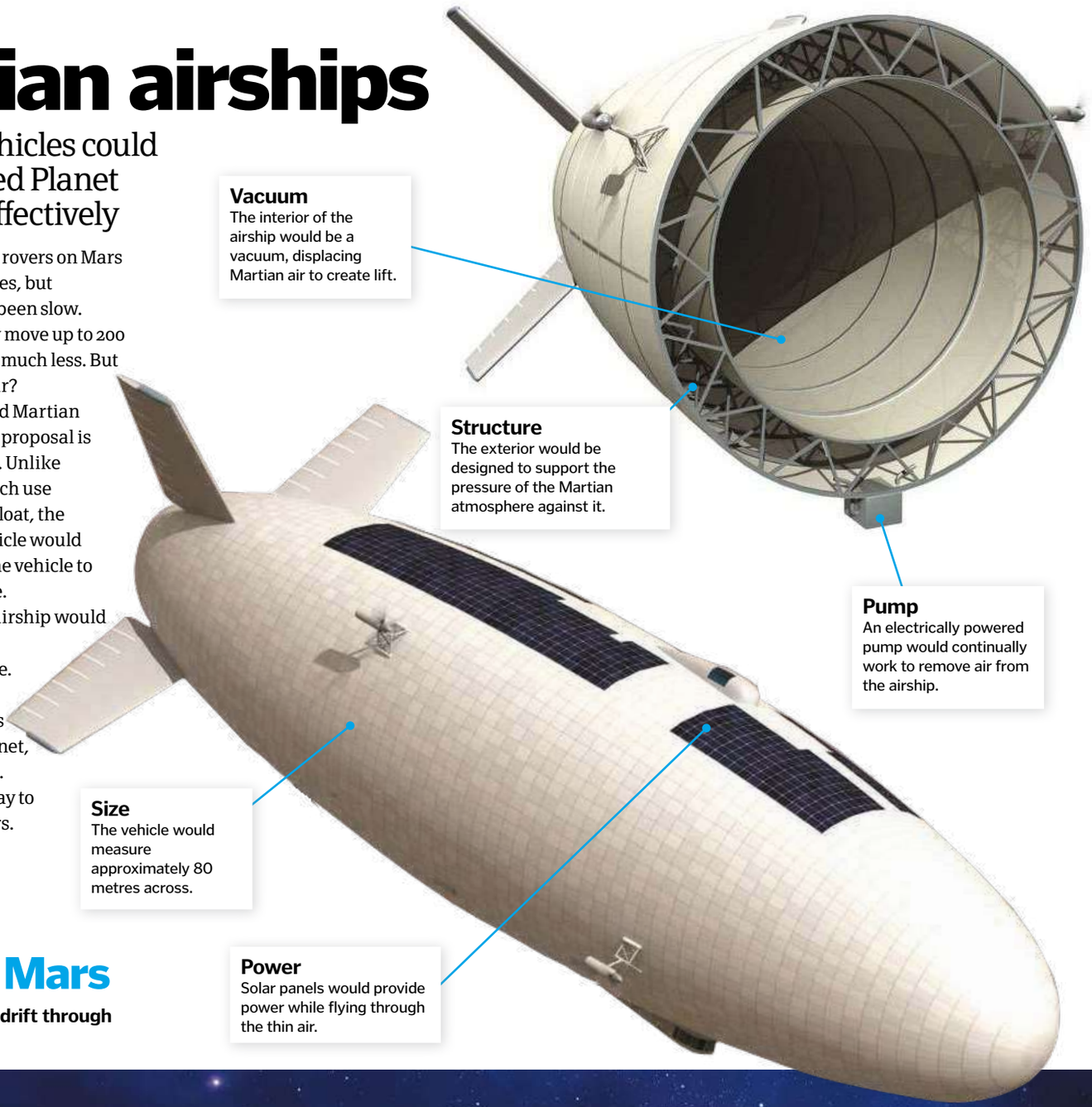
Martian airships

How flying vehicles could explore the Red Planet quickly and effectively

We've operated rovers on Mars for two decades, but progress has been slow. Typically, they can only move up to 200 metres a day, and often much less. But what if we took to the air?

That's the idea behind Martian airships, which a NASA proposal is currently investigating. Unlike standard balloons, which use helium or hydrogen to float, the vacuum inside this vehicle would provide lift, allowing the vehicle to hover above the surface.

On Earth, a vacuum airship would be impossible as our atmosphere is too dense. But on Mars, where the atmosphere is 100 times less dense than our planet, such an idea is possible. This may be our best way to robotically explore Mars.



Flying on Mars

How an airship would drift through the Red Planet's skies

Did life come from comets?

Mounting evidence suggests our origins may have been out of this world

Impacting comets could have delivered vital ingredients to our surface

How life on Earth began is a mystery. It is not clear whether the building blocks for life arose on our planet or were delivered by other means such as comets. In recent years, the latter has looked increasingly possible.

The big problem with the origin of life is we don't know how single molecules evolved into the complex multicellular life we see today. Comets could provide an answer.

One possibility is that they delivered clay particles to our planet, which acted as a catalyst and allowed single organic molecules to become complex. We've also found evidence for amino acids on comets. The team behind the Rosetta comet landing mission have already announced the discovery of the amino acid glycine and the element phosphorous, vital building blocks for the structure of DNA and therefore life on Earth.

When our Sun first formed 4.6 billion years ago it was surrounded by a disc of dust and gas. Some of this material froze within comets, which themselves contain some of the oldest material in our Solar System. We've seen evidence for organic molecules in other young systems, suggesting comets could well store these molecules. The only question then is where did these molecules come from?

Katherine Johnson

The human 'computer' who helped land man on the Moon

Katherine Johnson is a pioneer for African-American women in STEM

"I counted everything. I counted the steps to the road, the steps up to church, the number of dishes and silverware I washed ... anything that could be counted, I did."

From a very young age, Katherine Johnson had a fascination with numbers that would lead her to defy all expectations throughout her life. She graduated high school at just 14 and college at 18, securing degrees in both mathematics and French. After teaching for a few years she enrolled in a graduate maths programme, becoming the first African-American woman to attend the school at West Virginia University.

A year into the course she left to raise three daughters, but then, in 1952, a relative told her about an exciting new opportunity. The National Advisory Committee for Aeronautics (NACA), the predecessor to NASA, was hiring African-American women to solve maths problems. Katherine applied right away. She was soon hired as a 'computer' at the Langley Research Center, tasked with performing and checking calculations for flight tests.

As well as excelling at her work, Katherine also showed curiosity and assertiveness, always asking questions and asking to be included in important meetings. She ignored the racial and gender barriers of the time and became the first woman in the Flight Research Division to be credited as an author on a research report.

In 1958, the NACA became NASA and the space race began. Katherine was tasked with calculating the trajectory for sending the first American into space, and then the first American into orbit around the Earth. By this time NASA had begun using electronic computers to perform these tasks, but the machines could be a little temperamental. Before his Friendship 7 mission, astronaut John Glenn requested that Katherine personally recheck the calculations by hand, saying, "If she says they're good, then I'm ready to go."

The next challenge was to send humans to the Moon, and Katherine's calculations helped sync the Lunar Lander with the Moon-orbiting Command and Service Module to get the

A life of numbers

1918
Born Katherine Coleman in White Sulphur Springs, West Virginia, the youngest of four children.

1937
Graduates with highest honours from college, with degrees in mathematics and French.

1939
Becomes the first African-American woman to attend graduate school at West Virginia University.

1953
Begins working as a 'computer' as the NACA Langley Research Center.

1960
Becomes the first woman in her division to be credited on a research report.

Spaceflight trajectories and celestial navigation

THE BIG IDEA

Katherine's big passion was geometry, which was useful for calculating the trajectories of spacecraft. For the 1961 Mercury mission, she knew that the trajectory would be a parabola: a type of symmetrical curve. When NASA wanted the capsule to come down at a certain place, she said, "You tell me when you want it and where you want it to land, and I'll do it backwards and tell you when to take off." Subsequent orbital missions were more complicated, with more variables involving the position and rotation of the Earth, so Katherine used a celestial training device to perform her calculations.

A celestial training device was a globe within a globe that showed the key coordinates for navigation in Earth's orbit

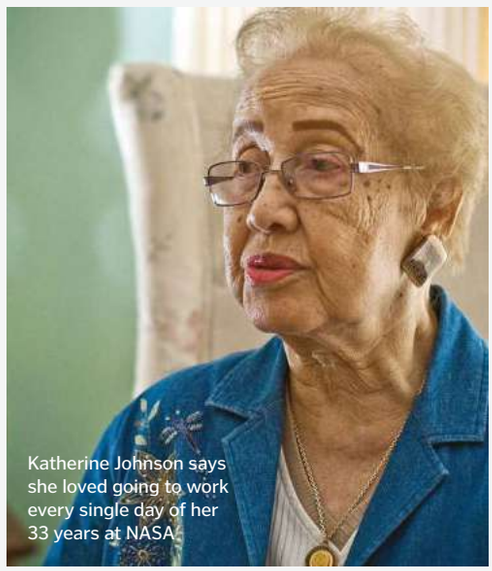
astronauts back to Earth. She also proved invaluable on the Apollo 13 mission, providing backup procedures that helped ensure the crew's safe return after their craft malfunctioned. She later helped to develop the Space Shuttle programme and Earth Resources Satellite and co-authored 26 research reports before retiring in 1986.

Today, Katherine often speaks to students about her extraordinary career and encourages them to pursue STEM. "Some things will drop out of the public eye and will go away, but there will always be science, engineering and technology. And there will always, always be mathematics. Everything is physics and math."

Katherine checked the accuracy of the work done using NASA's first digital computers

"Katherine showed curiosity and assertiveness, asking to be included in important meetings"

The 2016 movie *Hidden Figures* tells the story of Katherine's career at NASA



Katherine Johnson says she loved going to work every single day of her 33 years at NASA

5 THINGS TO KNOW ABOUT... KATHERINE JOHNSON

1
She had to move to attend school
Katherine's town didn't offer public schooling for African-Americans past eighth grade, so her family moved 193 kilometres away so that she could attend high school.

2
Her teachers recognised her potential
One of her professors, Dr William Schiefflin Claytor, encouraged Katherine to become a research mathematician and created a geometry class just for her.

3
She studied crashes
One of Katherine's first assignments in her job at the NACA was to analyse the black box data from crashed aeroplanes and work out what went wrong.

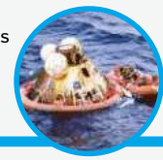
4
She was segregated due to her race
When she started at the NACA, Katherine and her African-American colleagues were required to work, eat and use restrooms separate from the white employees.

5
She can sing
Katherine sang in her church choir for 50 years.

1961
Calculates trajectory for Alan Shepard's space flight, the first American in space.

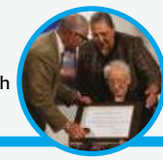
1962
Checks the calculations for John Glenn's mission to become the first American to orbit Earth.

1969
Provides the calculations that ensure the safe return of the Apollo 11 mission astronauts.



2015
Awarded the Presidential Medal of Freedom, America's highest civilian honour, by Barack Obama.

2016
NASA dedicates the Katherine G Johnson Computational Research Facility to her.



DOGS WITH JOBS

CLEVER CANINES AREN'T JUST FOR CUDDLING! THEIR KEEN SENSES AND SHARP MINDS MEAN THAT DOGS HAVE GOT WHAT IT TAKES TO WORK LIKE A PRO

Man's best friend has earned that nickname for a reason. They come with us through all walks of life, and our furry pals are also capable of shouldering incredible responsibilities in keeping us safe and helping us out. This is the story of the working dogs, the wonderful animals that use their amazing abilities to help us, all in return for a scratch behind the ear and a game of fetch.

Dogs work so well with us because of the bond that we are able to form with them. Thanks to their long-standing relationship with humans, dogs are able to read our emotions as well as interpret and react to them, and their drive to please is what builds this trusting foundation.

From Great Danes to Chihuahuas, dogs are all the same species, but their incredible diversity makes different breeds suitable for all kinds of work. From tiny vermin catchers in factories to huge cart-pulling mountain dogs, history is full of examples of why dogs are the ones for the job.

Modern pooch occupations involve lots more training and technology but they still play on a dog's instinctive behaviour, using their canine super senses to escape danger, weed out the bad guys and prevent disaster.

It sounds like a movie plot, but dogs are capable of all these things. Explosive detection dogs used by the Ministry of Defence (MOD), for example, go out on routine patrols and alert their handlers to improvised explosive devices (IEDs). This is just one example of a situation where humans rely on their canine counterparts to keep them safe.

Read on to find out just how much dogs can do for us and how they work on the job.

PC Paws

Despite being adorable, police dogs have some of the toughest occupations in the canine world

Dogs have been an important part of the fight against crime for centuries. There are a number of crucial jobs for the K-9 units, including both general-purpose and specialist work.

General-purpose dogs are very often breeds such as German shepherds and Belgian malinois. These are strong, capable and intelligent animals that can be quite intimidating if the job requires it! These dogs train hard to be able to find property and people, using their nose to search for things such as firearms or tracking suspects, as well as undertaking criminal work involveing apprehending suspects under the control of their handler.

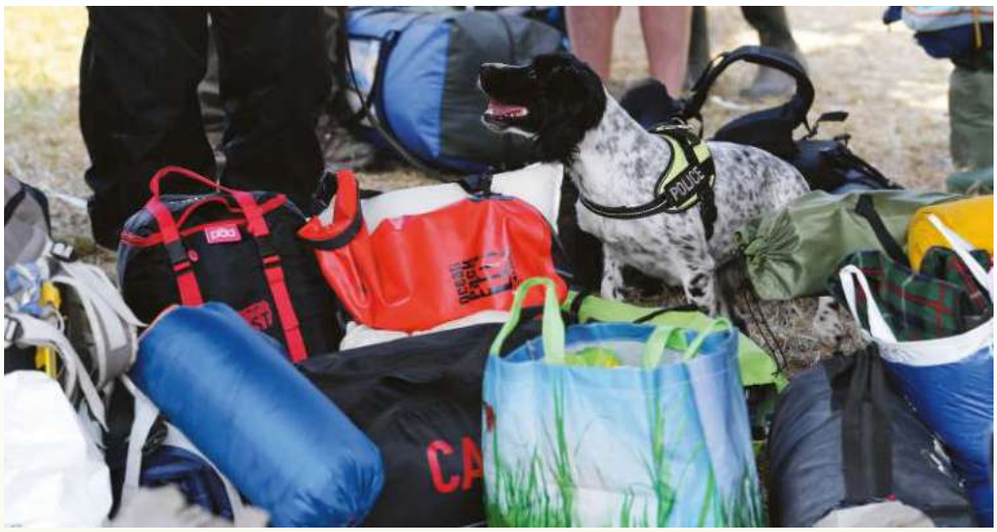
> *"Police dogs use their canine super senses to escape danger, weed out the bad guys and prevent disaster"*

Specialist dogs undertake tasks such as searching for explosives, drugs, cash and cadavers. The breeds for this type of work are often dogs with excellent scenting abilities.

As with any working dog, the bond with their handler is paramount. In the high-risk situations that police dogs work in, the handler needs absolute trust in the dog, so obedience and agility training is essential.

As well as working together, dog and handler will live together, too, and many retired police dogs remain as much-loved family pets once their time fighting crime in the name of the law is over.

Within the police force dogs have a number of jobs to do, from patrols to scenting work

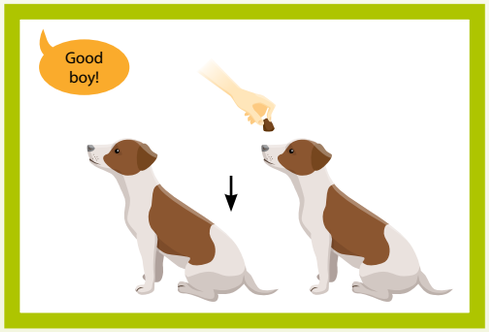


Police dogs are used at various events to search out illegal drugs and hazardous items

Detaining the suspect! Training is performed using protective suits to keep handlers safe and ensure that the dogs bite correctly

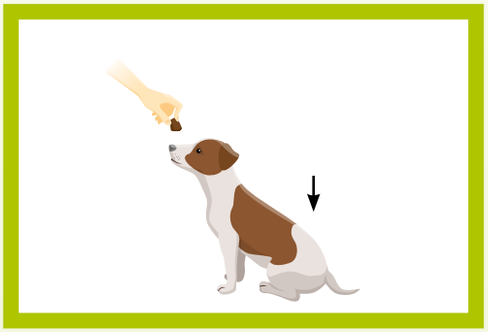
Teaching the basics

Every canine professional starts at the beginning. Here are a few different methods for heroes in training...



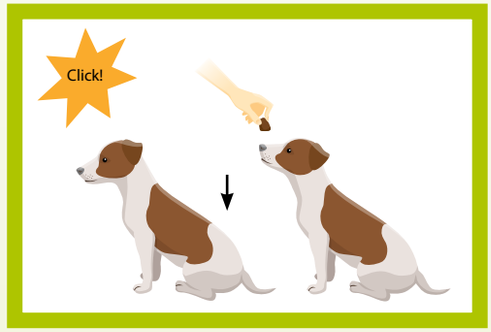
Guidance

Physically show the dog what you need it to do. For example, place your hand on its back and guide it to sit. Accompany this with a command, and then once the dog achieves it reward with plenty of praise and tasty treats.



Luring

If in doubt, treat to snout! Lure your pooch with a tasty morsel and show him the behaviour you need with the treat in your hand. Let the dog follow the treat and then reward and repeat.



Capturing

Wait until your dog does the thing you want. For example, when he sits of his own accord, accompany this with a sit command then follow immediately with a click from a clicker and a delicious treat!

Guide dogs

These caring pups provide essential guidance for those with visual impairments

Meet the expert
Samantha Gibbs is a dog trainer for the charity Guide Dogs, a UK organisation that trains and provides guiding dogs for people who are blind or visually impaired.

"It's absolutely phenomenal what they do," beams Samantha Gibbs, a dog trainer at the charity Guide Dogs' national training school. "I love my job," she goes on, "It's wonderful to see a puppy progress, mature and develop into a dog that's working confidently and independently, making complex decisions."

Sam's dogs come to her straight from the volunteer puppy walkers when they are around 14 months old. Sam works with them on three key areas: obedience, harness and guiding training, and the straight line principle, where dogs walk directly up to a curb to allow the guide dog owner to make location decisions.

"The fact that the dogs do that enables the owners to orientate themselves throughout their routes," Sam explains. "The curbs end up being little orientation markers for the owner and guide dog to move through their route."

So what is the quality that makes a great guide dog? "Every dog is different, which is what makes my job so fun," says Sam. "Every dog develops into their own type of guide dog, and each dog works differently. I wouldn't say that there is the 'perfect' guide dog as people are so varied – some want an energetic dog and others want a dog that's very laid-back." But there are a few traits that every guide dog must have.

"They have to be able to exhibit a high level of self control. Ignoring other dogs, people, smells, maybe food on the floor," explains Sam. Confidence is also key – a guide dog needs to be comfortable in all kinds of environments.

"You hear about our dogs having negotiated huge situations. When there was a terrorist attack in London one guide dog owner was on their way home. The roads were closed, but the dog negotiated a completely different route to get home safely." That's a very good boy indeed!

Guiding school

It takes these pooches around two years to go from pup to pro. Here's how the transformational training takes place

1 National breeding centre
The pups are born at the charity Guide Dogs' national breeding centre, a facility in Warwickshire where the puppies get the very best start to their working life.

2 Puppy walkers
At eight weeks old the pups go to live with volunteer puppy walkers. "They do a great job in socialising our puppies and exposing them to all kinds of things, like different kinds of animals, different types of people, and habituating them to different environments," says Sam.

3 Obedience and distraction work
This is the stage where the pups go to Sam for training. "They're normally about 14 months, and it's my job to take them from there," says Sam. "We spend around three weeks initially developing the obedience commands and we add in distractions, too."

Learn more
To find out more about the charity Guide Dogs, visit **www.guidedogs.org.uk**

"Every dog develops into their very own type of guide dog"

4 Guiding harness
The next step is introducing the dog to the guiding harness. "We want to train the dog to provide guiding tension through the handle," Sam explains, "because we need the dog to guide and step out [...] We start by teaching them to stop at the curb."

5 Straight line principle
This is an important part of the training, Sam explains. "It means that the dog will always continue to walk straight up to a curb," Sam says. "You won't see one of our dogs walk around a building line and go down a side road."

6 Advanced obstacle training
"The owner could give incorrect information and they may ask the dog to do things that aren't safe. So we introduce this concept by giving the dog a request when it's unsafe for it to do so and then reward the dog for ignoring the handler!"

Hearing dogs

Deafness and loss of hearing can be isolating and lonely, but hearing dogs are here to change that. Much like guide dogs, hearing dogs accompany their owners everywhere and use their sensitive hearing to act as their owner's ears, alerting them to sounds such as doorbells, telephones and alarms. Training starts from early puppyhood and includes lots of obedience and sound work.

Different dogs use different alerts. For example, smaller dogs will alert using two paws, whereas larger breeds will use a 'nose-nudge'. Dogs also need to learn to differentiate between different sounds; sometimes they need to lead their owner to the sound (like a doorbell) and sometimes, as in the case of a 'danger' signal such as a fire alarm, they need to use a different signal to keep safe.

Hearing Dogs for Deaf People is a UK charity that provides expert canine help and companionship for people with impaired hearing

7 Pickup standard
After around 16-19 weeks, Sam's pups will have reached 'pickup standard'. This means that they're ready for the next phase of their training. They leave the training facility to begin working with guide dog mobility instructors (GDMIs).

8 Second training phase
GDMIs work with the dogs for around 12 weeks, helping them apply their guiding skills to everyday situations. They are monitored throughout the whole process and their individual personalities are taken into account.

9 Matching process
The dogs are now fully trained and ready to be paired with their perfect match. The matching process can take some time as many factors are taken into consideration, such as character, temperament, lifestyle and environment.

10 Starting work
Once a successful match is found, guide dog and soon-to-be owner spend five weeks working with a GDMI, who trains the pair together and helps them get to know each other. Once qualified, the new pair start their life together.

Search and rescue dogs

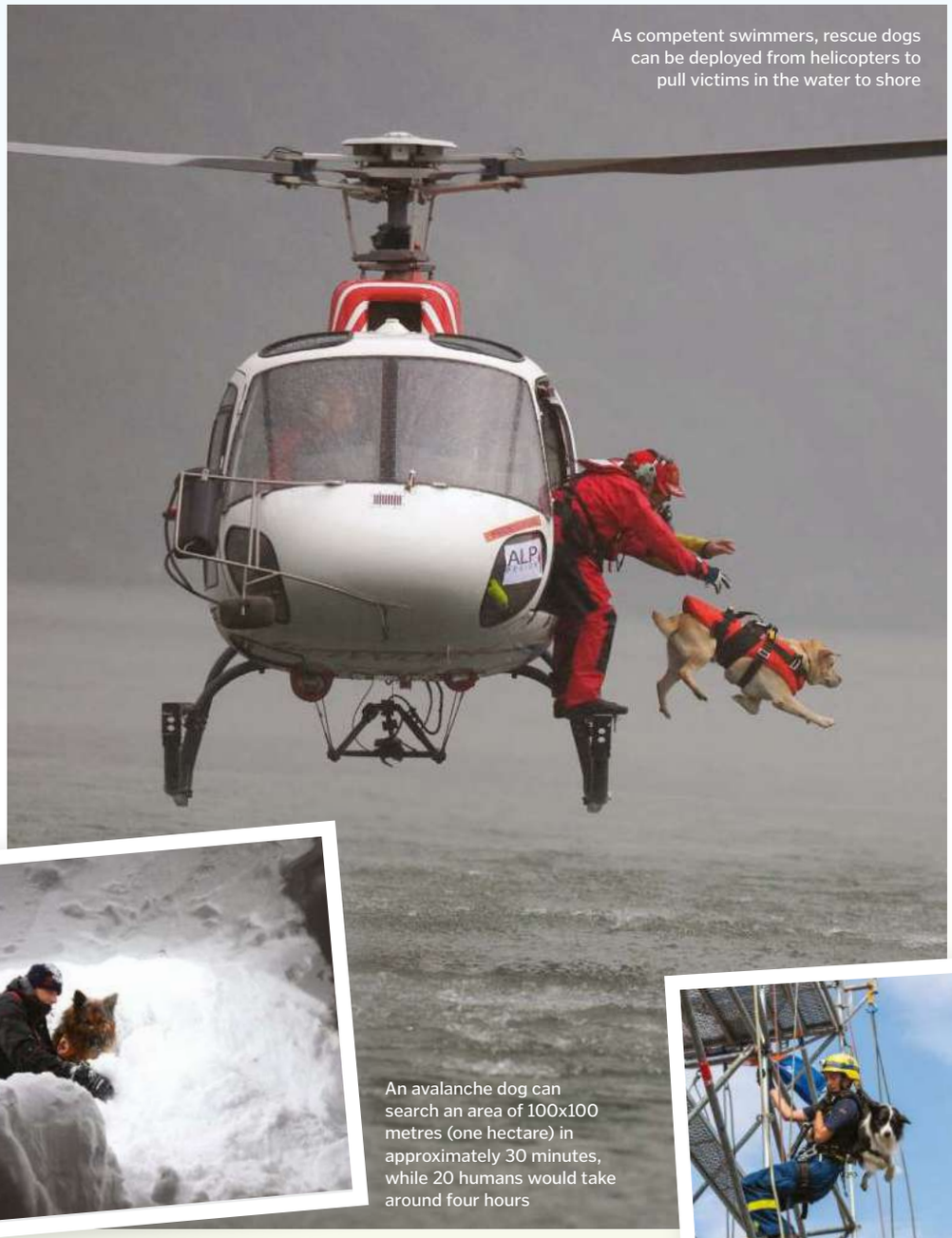
Thanks to their incredible senses, it's dogs that we humans turn to for help when we're lost

When lives hang in the balance, search and rescue dogs can be the difference between life and death. In hard-to-reach locations, small spaces, remote areas and dangerous terrain, four legs are almost always better than two.

Search and rescue dogs come in many different disciplines. There are tracking dogs, trailing dogs and scenting dogs, as well as water rescue dogs, avalanche rescue dogs, cadaver dogs and disaster dogs. Each has its own special set of skills and undergoes intensive training, but the mission is essentially the same: search, locate and alert.

When it comes to finding missing persons, dogs can use items of their clothing to identify their scent and follow the trail of particles that humans constantly leave in their wake. When they find live victims they will either indicate to their handler where the people are and wait with them, or they will consistently run between the found person and the handler to ensure help is on the way.

Training search and rescue dogs is a process built around a hide-and-seek style game. It's fun for the dogs, who relish the challenge. The breeds of choice for search and rescue are border collies, German shepherds and labradors, but that's not to say that other breeds wouldn't make a stellar searcher. Dogs just need a high play drive, a keen mind and an agile frame to deal with a fast-paced search over any terrain.



As competent swimmers, rescue dogs can be deployed from helicopters to pull victims in the water to shore

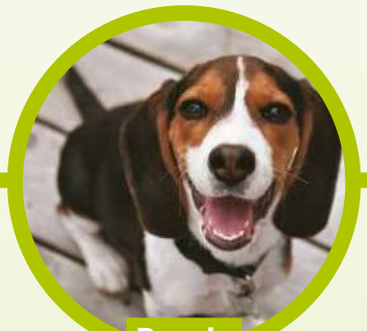
An avalanche dog can search an area of 100x100 metres (one hectare) in approximately 30 minutes, while 20 humans would take around four hours

Dogs are highly adaptable creatures, able to adjust to a whole array of situations, even abseiling with handlers to reach a search site

On the nose

All dogs have a keen sense of smell, but these particular breeds are a sniff ahead of the competition

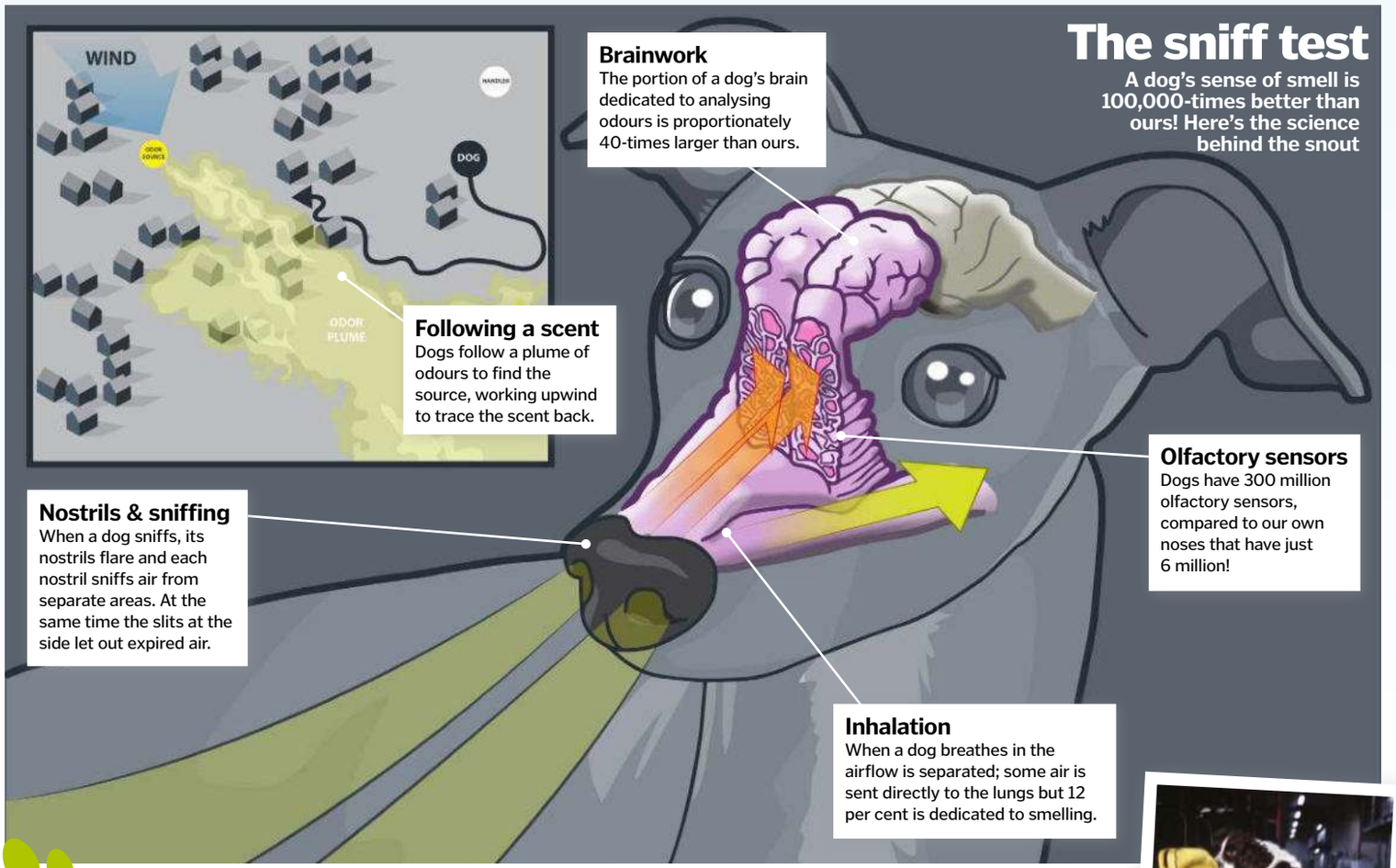
Bloodhound



Beagle

Coonhound

Springer Spaniel



Detection dogs

Guns, cash, drugs, explosives – these are the dogs who follow their nose to bust the illegal stash

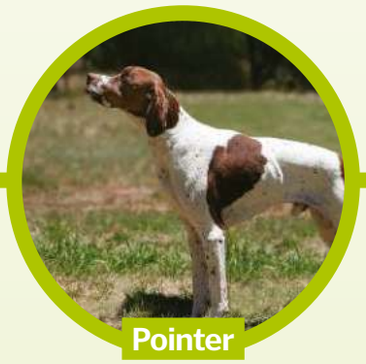
Detection dogs can home in on their imprinted scent even when there are millions of other scents around

Like search and rescue dogs, detection dogs search, locate and alert. But instead of human scent, they're exposed to different contrabands such as narcotics or explosives in order for them to recognise the smell and seek these items out.

Deployed by security organisations, police and the military, the breeds used are often gun dog types – those that have keen noses as well as a high search and retrieve drive. They are trained by gradually being rewarded with a game or a toy for finding their particular substance and alerting appropriately. They are then tested in many different environments to make sure they are ready for anything.

A relatively new type of detection dog is the medical detection dog. Dogs can be used for two jobs in medicine: biodetection and medical alerts. Alert dogs work much like assistance dogs do: they are partnered with a person who is diagnosed with a condition such as diabetes. The dogs' sense of smell allows them to detect changes in blood sugar imperceptible to us and alert their owner when medication is needed.

Biodetection dogs are being trained to recognise odours from diseases such as breast cancer in order to provide non-invasive early warnings. This is possible because dogs can recognise odours in parts per trillion – equivalent to discerning a teaspoon of sugar in two Olympic-sized swimming pools!


Pointer


Belgian malinois


German shepherd


Labrador retriever

Piper the Airport K-9

Every dog with a job is amazing, but there are some that have the coolest jobs of all

Piper is a nine-year-old border collie who lives in Traverse City, Michigan, US. He lives a pretty regular life, gets lots of runs on the beach, plenty of cuddles from his owner, Brian, and enjoys all the perks of being a much-loved pet. Oh, and he also oversees planes and helicopters landing on an airport runway, cool as a cucumber.

Piper and Brian work for Cherry Capital Airport, and the two of them are a major part of the airport's wildlife control team. Piper's natural instincts to herd and chase as a collie make him an excellent employee for wildlife control.

When they receive a call from air traffic control, Brian and Piper deploy to the airfield and Piper is set loose to do his thing. Chasing away the wildlife keeps the runways clear for busy air traffic, enhancing the safety of the busy airport as curious wildlife and aviation certainly do not mix.

K-9 kit

Piper's job requires a unique set of working accessories

Mutt muffs
Piper needs top-notch ear protection on the noisy airfield, and these specially designed doggy ear defenders work a treat.

K-9 trauma kit
Brian keeps everything Piper could possibly need in their deployment SUV, including a doggy medical kit in case of emergency.

Boots
The boots were designed to help protect Piper's paws from hot tarmac, rocks, and snow and ice in the winter. However, Brian and Piper don't use these any more. "We trained up for them, but they caused him to break a toe!"

"Piper was pretty good with small prop planes and jets, but helicopters were not his bag at first!"

Brian and Piper are part of the Wildlife Control Team at Cherry Capital Airport, Michigan, US. With a staggering social media following, we caught up with them to see how Piper likes both his job and his newfound fame.

Rex Specs goggles
"They're awesome!" Brian proclaims. "We use them on and off duty and they just protect his eyes from the Sun and everything here – plus they make him look pretty cool."

Vest
"This was donated to us by Spike's K9 fund," Brian explains. "It has a handle on the back, which is really useful for me to hoist him into the truck quickly when we respond to calls – it saves him jumping, too."

Identification
Piper's vest contains important identification and "It also provides a little abrasion protection for when he's running through the woods," Brian tells us.

At work with Piper

Get ready for the chase! The wildlife around this collie's airfield doesn't stand a chance

How did you and Piper meet?
Piper was actually a friend's dog that moved away and couldn't take him. I took him over when he was about four or five. I'd never had a dog before but Piper is such a good dog, so it was an easy decision.

What is your background and how did you get into wildlife control?
I work for the airport itself. My job really comes down to the safety and security of people using the airport. The safety portion includes wildlife control, and so I just added my own personal dog to help me out with that portion of my job.

How did you start training Piper to chase the wildlife?
There were two phases. One was that we had to do a lot of obedience training because we are working in a very unique environment here. Phase two was to bring him to the airport to do on the job stuff. We did a trial run for about a month in August 2014. Piper was pretty good with small prop planes and jets for the most part, but helicopters were definitely not his bag at first!

How do patrols work?
It's both reactionary and proactive. For the reactionary stuff we get a call from the air traffic control with a report of wildlife around the runways. Piper picked up a long time ago that when I use the radio to talk to the control tower it means we're going out in the field and he knows that means he gets to run. Which is good, because when we're going to react to something he has to be quick. So we get him all worked up in the back of the truck and when I release him he looks like a missile launched – it's great!
To be proactive, we go out and do routine patrols. It depends on all of the other functions of my job when we actually do it, but we try to get out as often as possible as that's the whole point of being here! It's discouraging to birds and foxes and all the other wildlife when there's a dog running alongsige a truck with flashing lights on it, so for that reason geese won't land in that area. And then also he's hunting for moles and voles and different vermin. The reason why we do that is because it's prey for larger animals like the fox. It's not like Piper can get rid of everything in the ground, but anything we can do really helps as it discourages the larger animals.

Piper must love his job?
Definitely! I think it's a dream job for a dog. We get to spend basically all day together and he gets to chase stuff.

What is your reaction to your amazing social media following?
That part of it still amazes me and continues to amaze me. I started the whole thing by thinking 'How can I work with my dog everyday?' That was number one, it was never really about the social media stuff. And also you can't make anything go viral, so for me, I love aviation and I love my dog and I think we're doing a pretty unique thing here, so I started the social media really because I thought aviation people might find it cool. I had no idea that it would turn into what it is! We are so thankful for everyone's support, and I can't stress enough how straight up lucky we are.

LEARN MORE

To follow Brian and Piper's work, search for Airport K-9 on social media or head to **www.airportk9.org**

Farming dogs

These working dogs have been our faithful servants for thousands of years

Some of the oldest uses for working dogs are with livestock. Farm dogs are often the hardiest dogs of all, guarding the animals and rounding up the stragglers through herding or driving. Even now, with modern machinery and pastoral innovation, there still isn't a more efficient way to herd a flock of sheep than with a keen collie at your side and a whistle in your hand.

Sheep dogs are trained from puppyhood and introduced to sheep very early on. The commands are then repeated and used until the dog understands the game. Border collies are the preferred breed for this work as they are quick, agile and very clever. The dogs need to understand and interpret curt commands and whistles over a long distance.

There are many other breeds of dog that were used for specific livestock. Finnish Lapphunds were bred for herding reindeer, and the Australian cattle dog is thought to be descended from wild dingoes, bred to drive livestock across the great expanses of the outback.

Along with farming, historically hunting was also a key activity where dogs were essential companions. Although now we don't need to track down our own food, the instinct to work alongside us in this capacity still drives dogs. Gun dogs are able to crash through the undergrowth to retrieve recreational hits, and in colder, snowier climes sled dogs are a huge part of Arctic culture.

Huskies were originally bred as a means of getting across ever-shrinking hunting grounds, and this willingness to work and pull has translated into a vibrant sledding community.

Border collies live to herd – they are a breed with very keen minds and a high work drive

"Dogs love us all as we are; they don't judge or discriminate"

Siberian huskies were originally bred as strong and sturdy dogs to pull a sled across Arctic hunting grounds

Therapy dogs

A visit from a furry friend when you're feeling low can make the world of difference

Unlike the rest of the hounds in our rundown of hero dogs with jobs, therapy dogs don't really require any special training. Volunteers and their happy canine pals visit places such as hospitals, care homes and schools to allow people to spend some time with a furry friend.

In schools, the presence of dogs has a very calming effect on children, especially in situations where learning can be stressful. In some schemes therapy pets listen to children read aloud. The dogs are a silent and non-judgemental presence, which can provide a real boost to a child's confidence.

In care homes and hospitals the presence of a wagging tail has profound benefits on both mental and physical health. Dogs can lift spirits, especially when people are very ill or old and frail. Dogs serve as a conversation starter, opening up social interactions for people, and the presence of a happy four-legged friend lowers feelings of loneliness and isolation. Dogs love us all as we are; they don't judge or discriminate, so people who are feeling down soon feel welcomed and needed by the dog.

The physical act of stroking a dog lowers the heart rate and blood pressure and promotes the release of oxytocin, a relaxation hormone. This means that in some cases, petting a dog can even reduce the amount of medication a patient needs. Dogs are also excellent at getting people moving – therapy dogs can go for walks with people that would otherwise be totally unmotivated to get outside.

A visit from a happy hound is one of the best ways to boost morale

Man's best friend

Our faithful, furry companions are descended from the grey wolf, *Canis lupus*. The domestic dog's name is *Canis lupus familiaris*, and they share 98.8 per cent of their DNA. However, despite the similarities, the domestic dog is very different to its wolf cousin, and that's due to our intervention.

One of the oldest known domestic dog skulls, found in Siberia, dates back 33,000 years. Scientists believe that this species was just on the cusp of domestication before it died out. But how did that happen?

There are a few different theories about how wolves and people came together. Wolves may have approached humans, tempted by the promise of food. But it's also possible that humans may have enticed the softer, friendlier and more docile wolves into their midst, realising the many benefits of having a canine companion.

It's also thought that this could have happened at different places and times in history. Either way, man and wolf, once partnered, were a force to be reckoned with.

Without dogs, where would we be? Dogs have had a huge part to play in our evolution

Cranberry bogs

Discover the farming methods used to cultivate one of the world's most versatile fruits

Cranberries are cultivated for juices, jams, sauces and other edible products in Europe, across North America and in some parts of South America. Some natural eating advocates claim that the little red fruit is one of the healthiest foods on the planet, partly due to its antioxidant properties.

Bogs are the natural habitat of cranberries. These wetlands have developed on poorly drained glacial deposits. Because of these conditions, bogs have a high water table and the ground can be saturated.

Many bogs are a source of peat moss, which often covers a large proportion of a bog's surface area. This moss decomposes slowly due to the wet conditions and causes the water around it to be relatively acidic.

Few plants are able to tolerate these conditions. Yet cranberries flourish in bogs because they are shallow-rooted, tolerant of flooding and may interact with mycorrhizal fungi to access the limited nutrients in the soil. Above ground, a cranberry plant produces thin, woody runners that spread across the surface and may live for decades.

The combination of this resilience and the cranberry's edible fruits make it an excellent crop. Commercially, cranberries are grown in specially prepared beds in boggy areas that are close to water sources such as ponds and reservoirs. The plants are cultivated on a bed of sand that is laid on top of the peat to stimulate growth and keep weeds down. In winter, the bed is flooded to protect the dormant stems from frost damage. After the beds are drained again in the spring, the flowers appear. If these are fertilised they will produce the berries, which start out white and then turn red throughout the summer and autumn.

Then, with Thanksgiving and Christmas just weeks away, the berries are harvested, processed and packaged just in time to add a sweet touch to turkey dinners. It's estimated that Americans consume over 5 million gallons of cranberry sauce every holiday season!

The berries have air spaces inside, which makes them float to the water's surface during harvesting

"In winter, the bed is flooded to protect the dormant stems from frost damage"

Harvesting cranberries

Most cranberries are 'wet harvested'. When the berries have ripened in late autumn, beds that were flooded the winter before are flooded again to a depth of around 45 centimetres. A special harvester is then driven through the bog to dislodge the berries from the plants. The loose berries float to the surface because of tiny air-filled spaces inside each one. Farm workers steer floating mats of berries towards an elevator that deposits them in a truck for transport. 'Dry harvested' cranberries are plucked off the stems by a machine and automatically bagged in sacks to be sold as fresh fruit.

A specially designed harvesting machine nicknamed the 'eggbeater' stirs up the water to dislodge the berries

Autumn leaves

Discover why some leaves change colour with the seasons and the chemistry behind these processes

Chlorophyll is the pigment found inside leaves that gives them their green colour. Absorbing vital energy from sunlight, chlorophyll helps to transform carbon dioxide and water into food via photosynthesis.

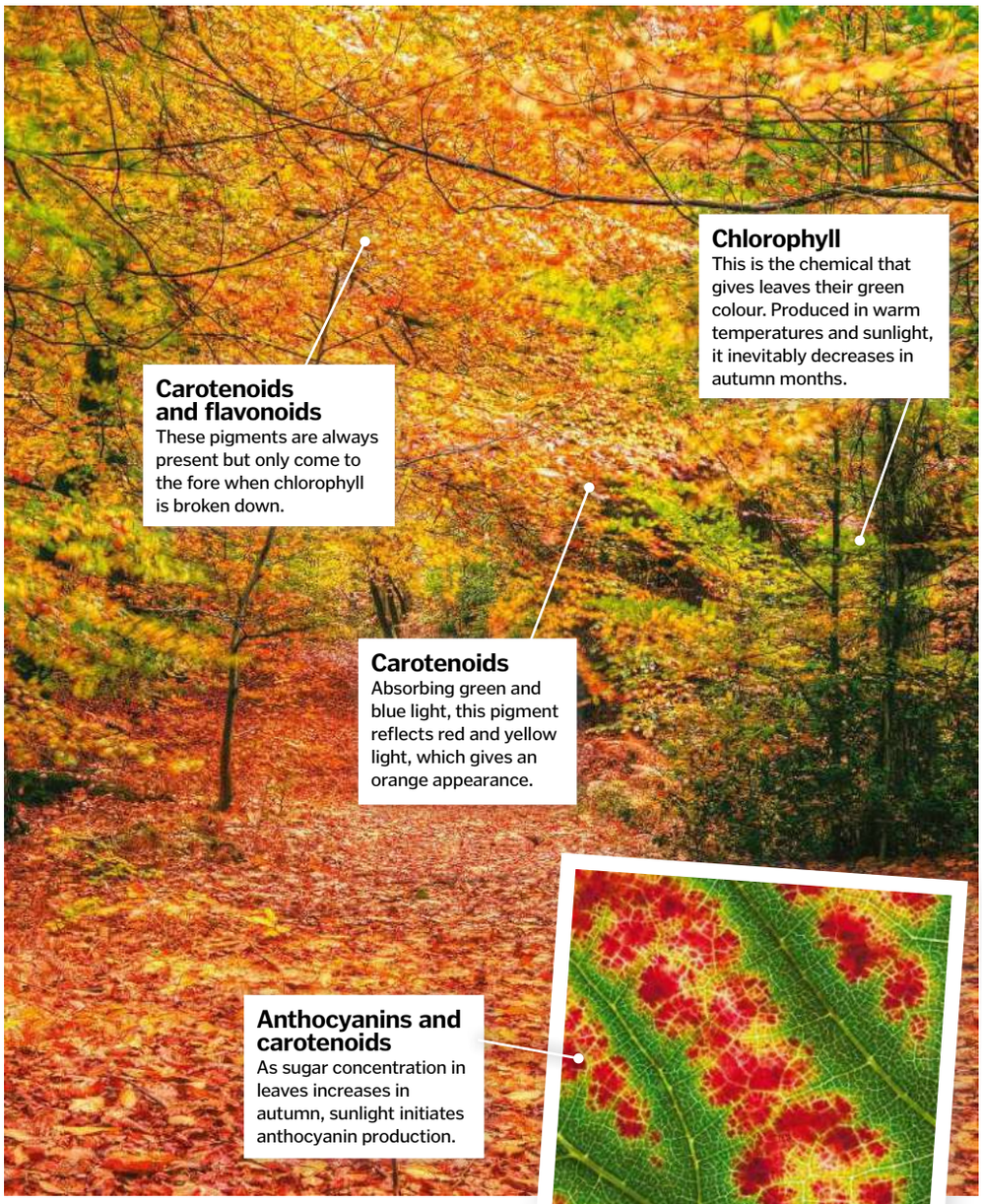
During spring and summer, when there is a lot of sunlight, plants make a lot of chlorophyll. But as daylight hours reduce and the temperature falls in autumn, a lack of light and water means that some plants stop producing chlorophyll.

As the chlorophyll breaks down, the green colour of the leaves gradually starts to disappear, eventually fading entirely. Yellow and orange pigments known as carotenoids, and red pigments known as anthocyanins, now become more visible.

Although these pigments were always present, the green chlorophyll had previously masked them. This is why we get such beautiful shades of orange and red leaves in the autumn.

Why leaves change colour

See how different pigments play a part in producing an autumnal display



This close-up shot shows the process of a leaf changing colour

TYPES OF FROST

From ground, air and hoar frost to the subtle differences between rime and glaze

Ground frost

When the surface of the ground, objects or trees has a temperature below zero degrees Celsius, (the freezing point of water), and the surface cools quicker than the air, ice forms on this surface. When this occurs, the ice is known as ground frost.

Air frost

When air temperature falls to or below the freezing point of water, air frost occurs. The air must be this temperature at a height of at least 1.25 metres above the ground in order for the ice particles to be considered air frost.

Hoar frost

When dew forms and then freezes on a surface with a temperature of or below freezing, a white frost consisting of blobs of ice occurs. When surface temperature reaches freezing before dew has started to form, a feathery type of hoar frost occurs.

NOT FROST

Rime

When below-freezing water droplets in fog come into contact with a surface that is also below freezing, they freeze almost immediately and form white, opaque, granular deposits of ice crystals.

Glaze

When super-cooled rain, drizzle or fog droplets come into contact with a surface at or below freezing point, the water accumulates and covers the surface, freezing relatively slowly to produce a clear ice coating.

“Speak French, Spanish or Italian as they are ***really*** spoken”

Now you can improve or maintain your French, Italian or Spanish with the bi-monthly audio magazines ***Bien-dire, Bien-dire Initial, Tutto Italiano*** and ***Punto y Coma.***

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HOW IT WORKS

ZOMBIE STAR

HOW IT WORKS

WALK WITH GIANTS

SILICON VALLEY

Discover how this region of California became the largest centre of high-tech industry on the planet

DID YOU KNOW? *Silicon Valley includes 30 cities and is home to no fewer than five universities*

Silicon Valley is a phrase that readily trips off the tongue. It's also a cliché that the press seems compelled to work into just about any story relating to certain high-profile computer companies. Like so many well-known phrases, though, it's a term which, to most of us, means very little. Here we examine how this land of technological wizardry came into being and how it grew to support thousands of high-tech companies with a combined value measured in trillions of dollars.

Geographically, the region itself is not particularly well-defined. Silicon Valley runs from the southern edge of San Francisco for 80 kilometres along the Santa Clara Valley to San Jose in the southeast. Residents of San Francisco are adamant their city is not part of Silicon Valley, although that's a moot point; with the region's expansion north, that could change.

The word silicon stems from the time that the area was home to several large semiconductor manufacturers such as Intel and AMD. However, with software and internet companies now every bit as important to the region, it's clear that what really sets this area apart is technological innovation and entrepreneurship. Industry commentators have identified that sense of technical innovation dating back to well before most people had ever heard of digital electronics, let alone computers.

The first ever ship-to-shore message to be received in the US by radio was from the San Francisco lightship announcing the return of the American fleet from the Philippines after the Spanish-American War of 1898. A decade later, America's first radio station to broadcast a regular schedule of programmes was KCBS in San Jose, which started its transmissions in 1909. In an era when radio communication had previously been via Morse code, this enterprise involved a high degree of inventiveness.

At around the same time the Federal Telegraph Company was founded in Palo Alto, California. Boasting Lee de Forest – the inventor of the valve and arguably the father of electronics – as one of its employees, the company was influential in developing broadcast technology.

Entrepreneurship in the region can also be traced back to the very early days to a time when electronic computers were little more than theoretical concepts exercising the minds of academics like Alan Turing. A plaque outside a

Steve Jobs co-founded Apple in 1976 in the garage of his parents' house in Los Altos with Steve Wozniak

"The transistor would soon replace the valve as the cornerstone of electronics"

Facebook's four-hectare HQ in Menlo Park features the largest open-plan office in the world

THE STORY OF SILICON VALLEY

Events that shaped the global centre of technology

1899
The US's first ever ship-to-shore radio transmission is received in San Francisco.

1909
KCBS in San Jose becomes America's first radio station to broadcast on a regular basis.

1912
Lee de Forest invents the valve in Palo Alto and kick-starts a new science in the form of electronics.

1930s
Professor Frederick Terman encourages his students at Stanford to become entrepreneurs.

1938
William Hewlett and David Packard take Terman at his word and set up Hewlett Packard in a garage.

1956
William Shockley, co-inventor of the transistor, starts a company to develop silicon transistors.

garage in Palo Alto claims to be the birthplace of Silicon Valley, this being the place where, in 1938, Stanford University graduates William Hewlett and David Packard started to develop their first product. That initial device, a piece of electronic test equipment called an audio oscillator, had nothing to do with digital electronics, using valves instead of transistors, but their company, Hewlett Packard, would grow to become today's fifth largest IT company.

Almost 20 years would pass from that garage in Palo Alto and a development that would change Silicon Valley forever, and in so doing

> *"What really sets this area apart is technological innovation and entrepreneurship"*

make that phrase a lot catchier than Valve Valley ever would have been. That innovation was the invention of the transistor, which would soon replace the valve as the cornerstone of electronics, paving the way towards increased circuit complexity, plummeting prices and much-improved reliability.

This development didn't happen in California, though, but at AT&T's Bell Labs in New Jersey, and what's more, that first transistor was made out of the element germanium. This all changed when co-inventor, the physicist William Shockley, moved to Mountain View, California. Here, in 1956, he set up the Shockley Semiconductor Laboratory, where he developed the superior silicon transistor. His company wasn't a commercial success, and just a year later eight employees left to form Fairchild Semiconductor.

Fairchild might no longer be a household name but the impact it had in those early days – which continues to the present day – was profound. The invention of the transistor led to the development of the integrated circuit, or IC, which was basically a working circuit made out of multiple transistors on a single piece of semiconductor material. Fairchild's Robert Noyce would later produce the first ever IC to be made from silicon. Then, in 1968, together with colleague Gordon Moore, Noyce left Fairchild to set up Intel Corporation, also based in Mountain View.

Since the company is best known for its microprocessors, it might come as a surprise to learn that Intel's first products were memory chips: microprocessors had yet to make their first appearance. These memory chips were certainly used in computers and were much cheaper than the magnetic core memories that preceded them, but those computers were mainly built out of individual transistors, wired together in their thousands. No wonder a cheap mini-computer of that era would set you back over £100,000 ($132,250) in today's terms. But the most important change yet, a change that would revolutionise computing, was about to take place, and it would happen at Intel.

The 'Intel Trinity' of Andy Grove, Robert Noyce and Gordon Moore (left to right) pictured here in 1978

Just three years on from the company's inception Intel ran an advertisement announcing "a new era in integrated electronics". The advertisement was for the 4004, the world's first microprocessor. That pioneering device was a 4-bit processor (today's chips have a 64-bit architecture); it ran at 740 kilohertz, a far

If it were a country, California would boast the third highest population of billionaires in the world

Google's HQ in Mountain View is known as the Googleplex, and is also the HQ of its parent company Alphabet Inc

© Intel; Getty; Thinkstock; Alamy; WIKI

1968
Intel is founded by Robert Noyce and Gordon Moore. Their first product is a 64-bit memory chip.

May 1969
AMD (Advanced Micro Devices) is founded, further establishing Silicon Valley's reputation.

Oct-Dec 1969
ARPANET is trialled. Stanford University plays a role, helping form the foundation of the internet.

1971
Intel announces "a new era in integrated electronics". The microprocessor is born in Silicon Valley.

1974
American journalist Don Hoefler is the first to coin the phrase 'Silicon Valley' in print.

1974
Xerox develops the graphical user interface in Palo Alto. Apple jump onboard with the Mac.

1977
Apple II is the company's first successful product and paves the way to personal computing as we know it.

cry from today's 1-3 gigahertz; and it had 2,300 transistors compared to several billion in today's chips. Despite all that, the saying that "mighty oaks from little acorns grow" has never been more appropriate.

So, by the early 70s, Silicon Valley was developing silicon chips, and those chips were starting to find their way into computers. Needless to say, Intel would soon be joined by a whole raft of other semiconductor manufacturers. Some, like AMD, are still well-known today, while some, like Zylog, are now producing more niche products. Others, such as MOS Technology, while hugely influential at the time, are now consigned to history. Changes were afoot in many places.

When Intel and its competitors first started producing silicon chips, the devices were used in hugely expensive computers like the mainframes that served whole companies and in the mini-computers that would be operated by single departments. Most of the key players in these markets were not located in Silicon Valley but on the east coast or the Midwest. Mainframe giant IBM was based in New York State, while mini-computer pioneer Digital Equipment Corporation (DEC) was to be found in Maynard, Massachusetts. As these giants continued to grow a game-changer emerged on the scene.

While it never went on to become a commercial success, the Altair 8800 was genuinely groundbreaking in being the first machine to be recognised as a true personal computer. This Intel 8080-based machine cost $395, which was a lot of money when it launched in 1975, and it came in kit form that enthusiasts had to solder together themselves. Its manufacturer, MITS, wasn't based in California but in Albuquerque, New Mexico, but where MITS led others soon followed.

Without a doubt, the single most influential company to enter the micro-computer market of the mid-70s was Apple. Famously founded by Steve Jobs and Steve Wozniak in a garage in Los Altos – seemingly something of a tradition in the early days of Silicon Valley – the company's first product was the Apple I personal computer, which was introduced in 1976.

Unlike the Altair 8800, the Apple I was fully assembled, but you only got the motherboard so you had to add your own keyboard, case and monitor. Only 200 were ever sold, but it paved the way to its successor, the truly innovative and hugely successful Apple II. Here was a computer that was fully assembled and housed with a keyboard – all you had to do was plug it into a TV to act as a monitor and an audio cassette player that provided storage. At $1,298 for the 4k version, or $2,638 (over $11,000/£8,500 in today's terms) if you wanted 48k of memory, it seems incredible it sold in such quantities.

Fuelled to no small extent by the introduction of the VisiCalc spreadsheet, an ancestor of the Excel spreadsheet program, this moved the Apple II from being a hobby machine to a personal computer that could be used in business. From 1977 to 1980, Apple's sales of this, its only product, went from $775,000 to $118 million. The rest, as they say, is history.

To see another vital aspect of Silicon Valley's success, we need to wind the clock back to look at one more trend that was occurring in parallel with the growth of personal computing. In 1969, the US military's ARPANET underwent its first trials. This was an early wide-area computer network, and in time it would form the basis of the internet. That initial network comprised just four sites – one in Utah and three in California, including one at the Stanford Research Institute, which at the time was part of Silicon Valley's Stanford University.

By the late 80s, moves were afoot to open up the internet to commercial use. The first internet service providers were not all concentrated in California but were scattered throughout the US. This perhaps wasn't too surprising – breaking down geographic barriers has been a key feature of the internet.That isn't to say that Silicon Valley hasn't played a huge part in the growth of internet-related tech, though – far from it.

Apple's new 70-hectare campus, known as Apple Park, is almost complete. Its 260,000 square metres of office space will house 13,000 employees

"The dream is still alive and, if anything, the region's supremacy is only growing"

1982
Adobe is set up, helping to establish a software industry in Silicon Valley to augment its hardware roots.

1984
CISCO is founded to provide networking equipment. Silicon Valley is gearing up for the commercialisation of the internet.

1995
Alta Vista launches and soon becomes one of the most successful companies in the up-and-coming search engine market.

1998
A year after the Google search engine goes live, Google is established as a company.

2004
Facebook makes its entrance. It isn't the first social media company but it soon becomes a dominant force.

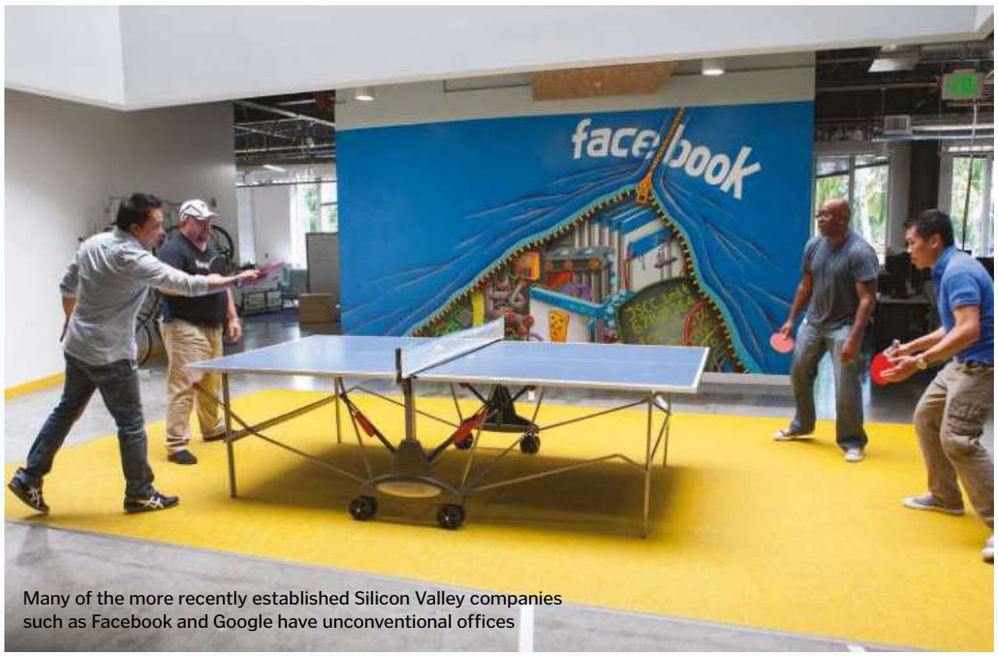
2016
Waymo (right) is spun off to commercialise Google's driverless car programme. Silicon Valley becomes even more diverse.

Today, the phrase 'search engine' is virtually synonymous with Google, but it hasn't always been this way. Founded in 1995, Alta Vista, based in Palo Alto, was, in the mid-90s, one of the world's most-used search engines. Contemporary Yahoo! – who eventually acquired Alta Vista by purchasing its parent company Overture in 2003 for $1.63 billion – was another of the early greats in the world of search engines and was also based in Silicon Valley.

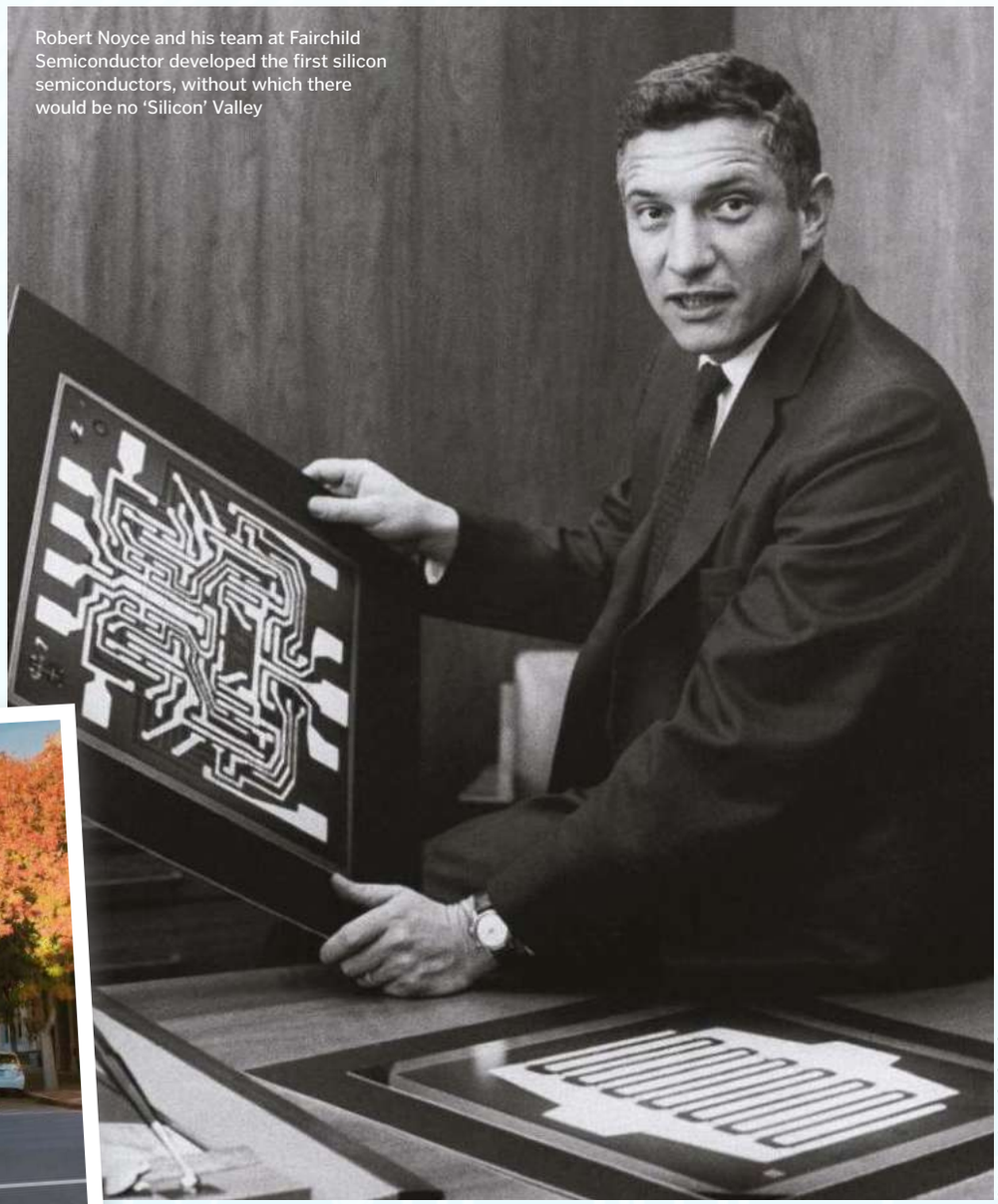
Big names in Silicon Valley also include manufacturers of the hardware that beavers away in the background making the internet tick. Many of the routers or access points that bring the internet into our homes are manufactured by Cisco, Netgear and Ubiquity, all of which are based in the region. And when we turn our attention to Silicon Valley's most recent success stories – the growth of social media and file sharing services – once again we see the supremacy of this illustrious region, with Facebook, Twitter, WhatsApp, Google, YouTube and Instagram all founded and based either in the Valley or nearby San Francisco.

The near dominance of Silicon Valley in the world of social networking suggests that the dream is still alive and, if anything, the region's dominance is only growing. The story of Google – with its corporate fingers in pies as diverse as self-driving cars, search engines, cloud-based storage, mapping and navigation – rather suggests that Silicon Valley's future is going to be even more varied than its past.

Predicting the future is always difficult, especially in the world of technology, so our suggestion of what Silicon Valley's future holds is made with some trepidation. However, we can't help but notice that Google has recently set up a company called Waymo to further develop its driverless cars, while electric car manufacturer Tesla is based in Palo Alto. With cars migrating from petrol engines and mechanical engineering to electric engines and software, could Silicon Valley become the new Detroit?



Many of the more recently established Silicon Valley companies such as Facebook and Google have unconventional offices


Robert Noyce and his team at Fairchild Semiconductor developed the first silicon semiconductors, without which there would be no 'Silicon' Valley

Pipe organs

Ancient technology that uses a complex system of pipes and valves to make music

The sound of an organ is made by the column of vibrating air inside each pipe, and the instruments have four crucial parts: pipes, a chamber, mechanical pressure, and a keyboard. Amazingly, the first one was invented in ancient Egypt by a Greek engineer around 300 BCE.

The challenge at the time was to find a way to make multiple wind instruments play simultaneously without the need for a whole orchestra of people. So the engineer constructed an air-filled chamber that could be pressurised using pumps and water, with a series of keys and valves that allowed the air to rush through different instruments at different times. It was called the hydraulis, and it spread across the ancient world.

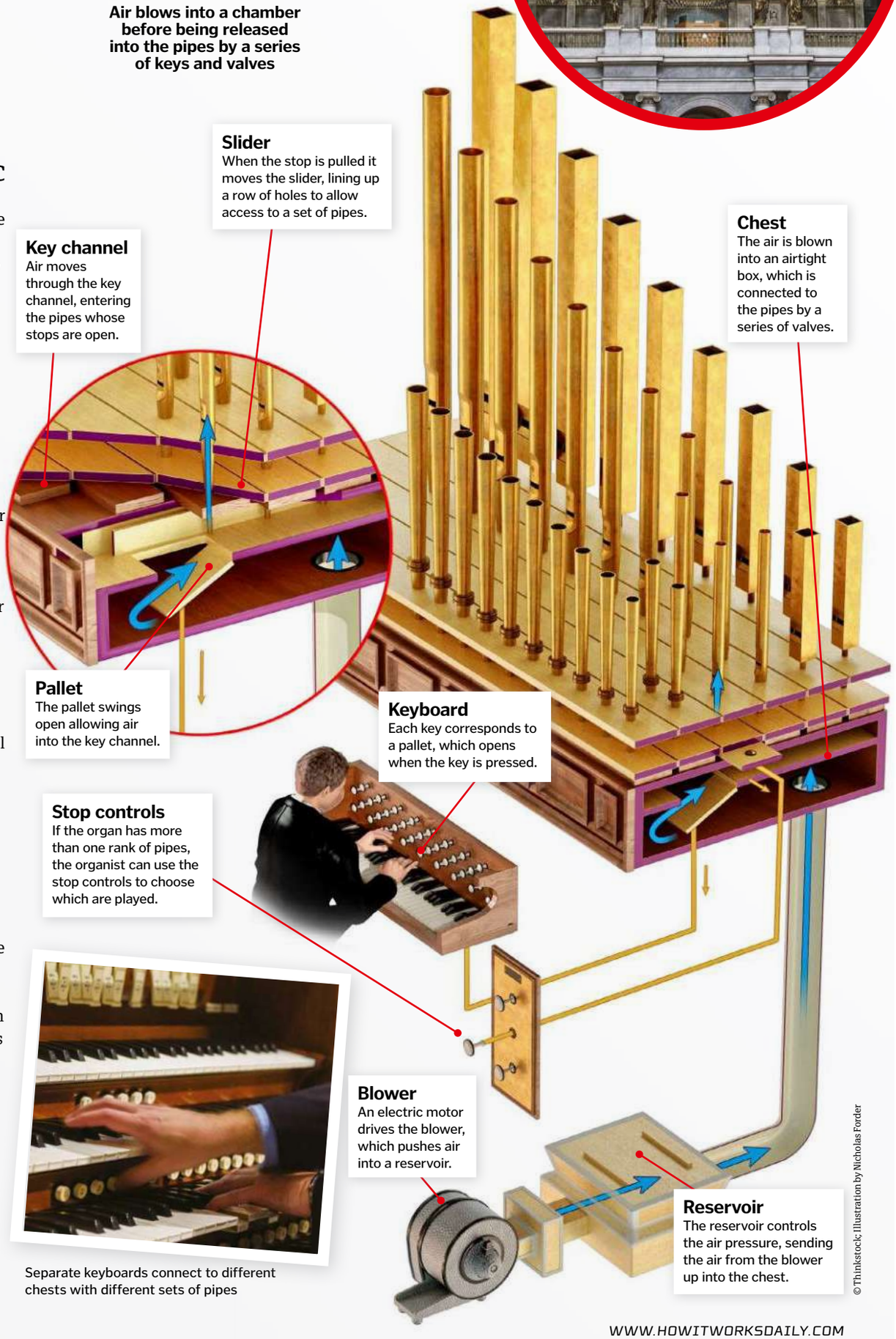
The Romans later swapped the pumps for bellows, and in medieval times even more developments were made, including portable organs with bellows played by one hand and the introduction of church organs to play music for the community. By the Renaissance these enormous instruments had started to introduce stop controls, allowing multiple sets of pipes to be played at once, creating rich, multi-layered sounds.

Modern pipe organs are based on the same principles and the sounds they produce are varied by changing the design of the pipes themselves. Narrow and straight pipes have more harmonics than wide and tapered pipes, while metal pipes with a high tin content make a brighter sound than wooden pipes. Flue pipes sound more like a flute or recorder, while reed pipes have a mechanical clarinet-like reed at the base.

The pipes in the organ of the Esztergom Basilica, Hungary, range from 7mm to 10m in length

Inside a pipe organ

Air blows into a chamber before being released into the pipes by a series of keys and valves



Slider
When the stop is pulled it moves the slider, lining up a row of holes to allow access to a set of pipes.

Key channel
Air moves through the key channel, entering the pipes whose stops are open.

Chest
The air is blown into an airtight box, which is connected to the pipes by a series of valves.

Pallet
The pallet swings open allowing air into the key channel.

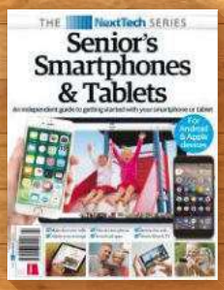
Keyboard
Each key corresponds to a pallet, which opens when the key is pressed.

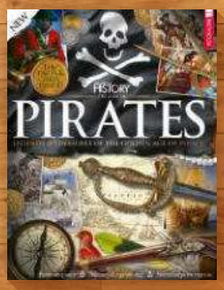
Stop controls
If the organ has more than one rank of pipes, the organist can use the stop controls to choose which are played.

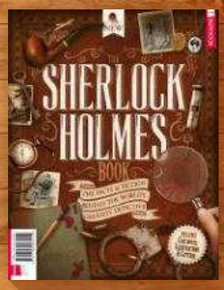
Blower
An electric motor drives the blower, which pushes air into a reservoir.

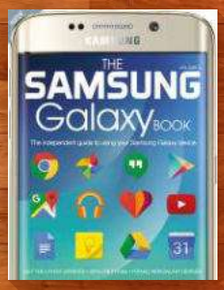
Reservoir
The reservoir controls the air pressure, sending the air from the blower up into the chest.

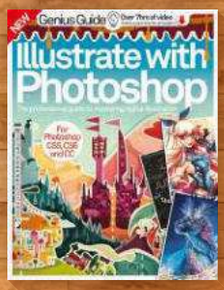
Separate keyboards connect to different chests with different sets of pipes

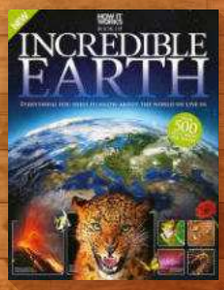












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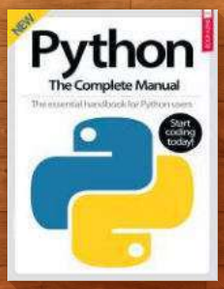

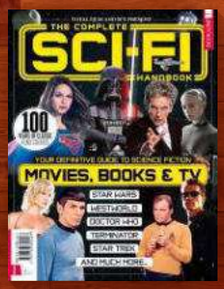

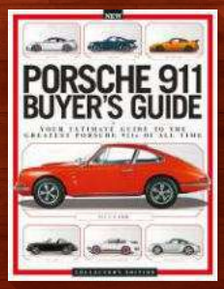

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Learn to code with Raspberry Pi

Meet the mini computer that's making a huge impact

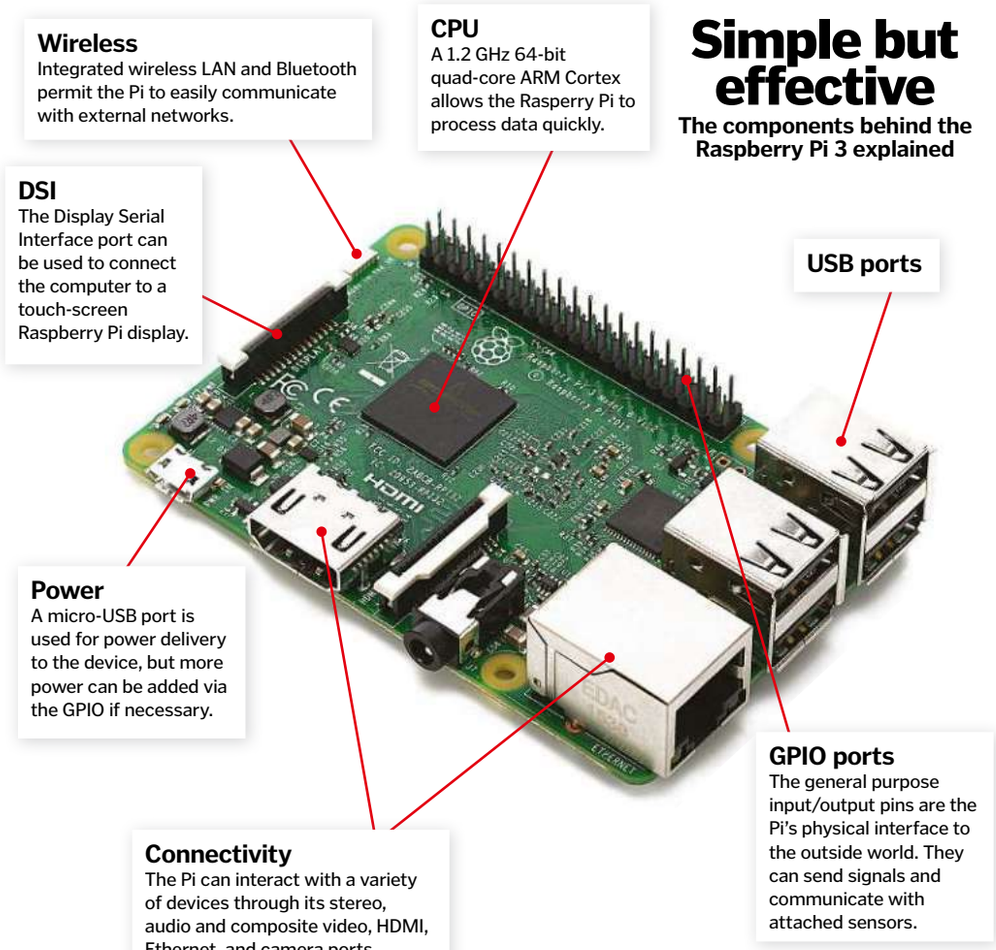
Computers are everywhere in the modern world. For office jobs we use desktop computers; when we're at home we use laptops and tablets; and when we're on the go we use smart phones. And from this huge realm of technology we have more advanced software and hardware constantly incoming. We learn how to use these tools, but many of us are ignorant as to how they work.

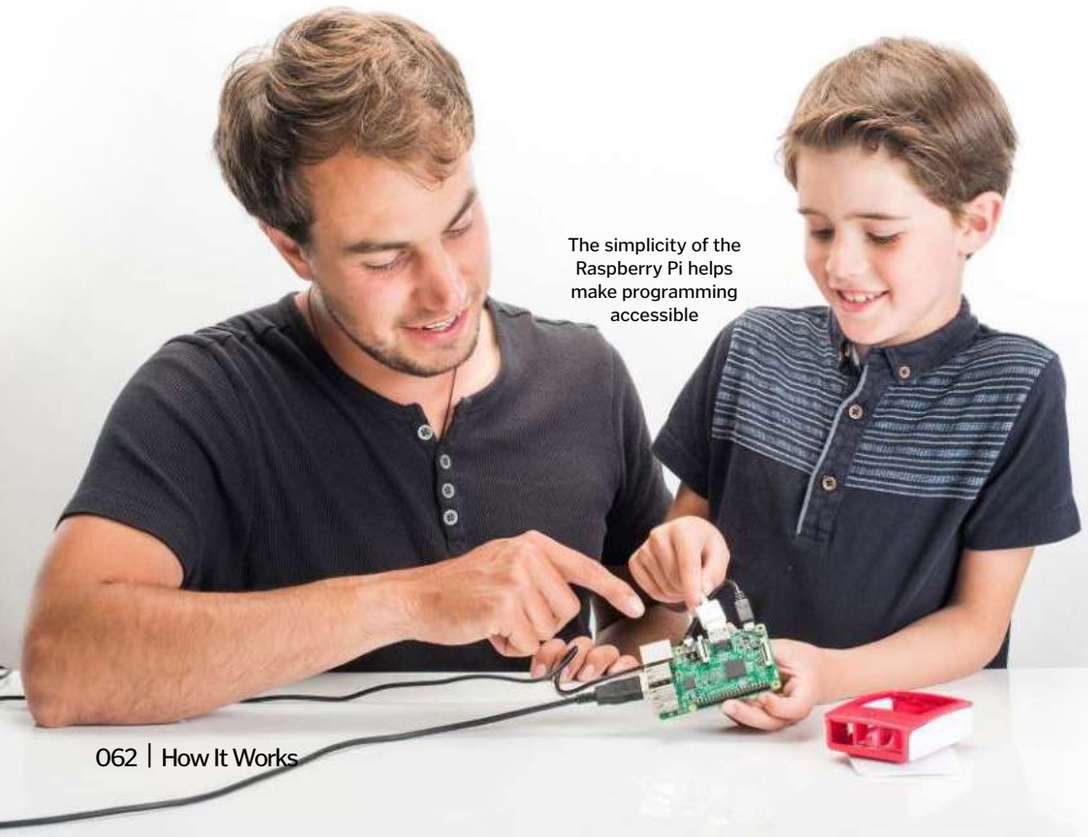
For those who would like to get involved with computing and computer programming, the maker of the Raspberry Pi, Eben Upton, felt that we could all learn a lot from an inexpensive, basic and versatile computer, saving us from tearing our current computers to pieces just to get a look at what's inside. The Raspberry Pi itself is essentially a credit card-sized circuit board with essential components attached, but it is this simplicity that allows it to be used in so many ways.

For beginners, the Pi can be connected to a monitor, keyboard, mouse and power source and used as a simplistic computer. Running on the Linux operating system and with coding languages installed, students can learn to write programs and create video games. And for more expert users, the Pi can be attached to an array of different mechanisms to create things like 3D scanners, talking toys and even Pi-powered electric skateboards! So once you've entered the computing world, who knows what exciting pieces of software you could end up creating.

Simple but effective

The components behind the Raspberry Pi 3 explained





The simplicity of the Raspberry Pi helps make programming accessible

Top 5 activities for learning on your Raspberry Pi

1 Turtley amazing
Get to grips with the common coding language python with a Turtle module, which will teach you how to draw shapes, patterns and spirals.

2 Minecraft Pi
Play a special version of *Minecraft* that lets you control your character, place building blocks and interact with the world using the python interface.

3 Talk like a pirate
Use a jQuery script to create a 'normal language to pirate speech' translator, which will get you fluent in pirate lingo in no time.

4 Scratch
Learn the visual programming tool that allows you to create your very own video games using an accessible drag-and-drop interface.

5 Story time
Use the python coding language to create your own interactive story game that others can play through and try to complete when you're done.

Moore's Law

The law that has defined computing power for 50 years

In the 1960s, Intel co-founder Gordon Moore realised the breathtaking potential of computer circuits. Inside his own company and around the world, he noticed that designers had been adding more components onto a single circuit by shrinking the parts. Each time this was done the processing power jumped, and it was this surge that led to his 1965 prediction that processing power would double every year.

This prescient statement was later amended to every two years after the industry had made its initial mammoth strides, but over the next five decades Moore would be proven right time and again.

Today's top microchips have billions of transistors separated by mere billionth's of a metre, which begs the question of just how far computer power will go.

Milestones in computing

Key events that show how Moore's Law has stood the test of time

1965
Gordon Moore publishes an article that predicts computing power will double every year. This is later refined to every two years.

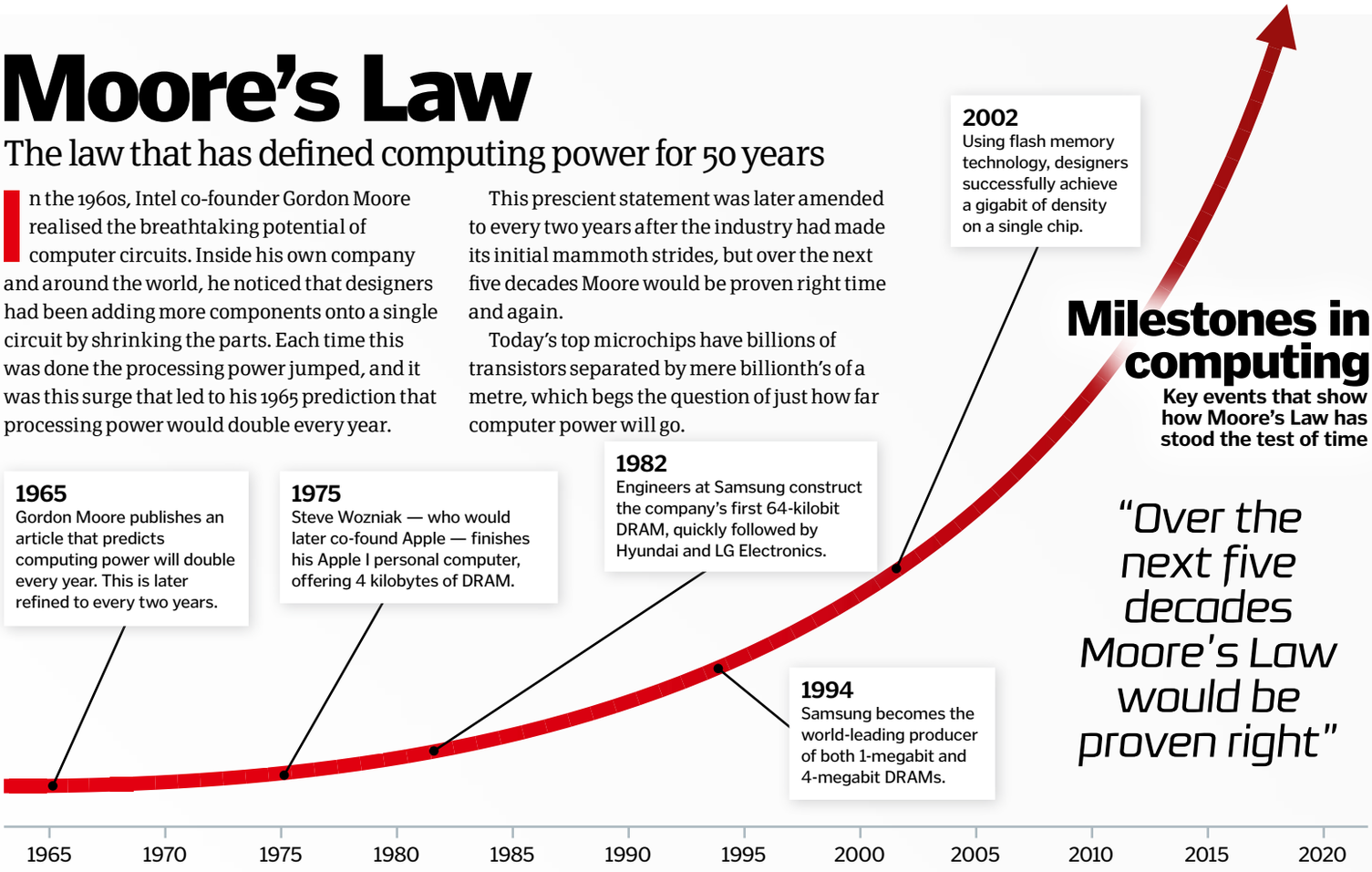
1975
Steve Wozniak — who would later co-found Apple — finishes his Apple I personal computer, offering 4 kilobytes of DRAM.

1982
Engineers at Samsung construct the company's first 64-kilobit DRAM, quickly followed by Hyundai and LG Electronics.

1994
Samsung becomes the world-leading producer of both 1-megabit and 4-megabit DRAMs.

2002
Using flash memory technology, designers successfully achieve a gigabit of density on a single chip.

"Over the next five decades Moore's Law would be proven right"



Smart meters

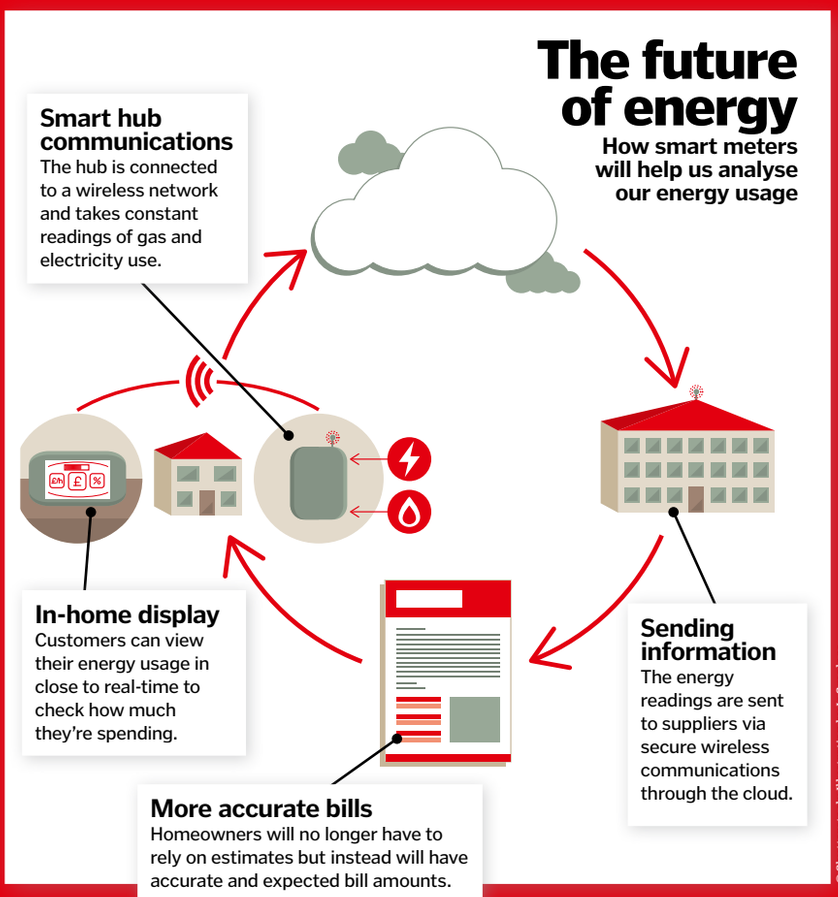
The clever gadgets that are soon to join every household in the UK

By 2020, every home in the UK will be offered a smart meter to help keep track of energy usage. Instead of manually collecting gas and electricity readings, these gadgets will automatically calculate and transmit your household energy usage to your suppliers via a national communication network called the Data Communications Company. The meter's data will be processed autonomously by the supplier and then sent back to an in-home display. This will display the important readings, such as kilowatt-hour use and the cost of current energy usage, putting an end to today's inaccurate estimates and helping you keep track of how much energy you're using in near real-time.

In-home displays will provide near live readings of energy usage

The future of energy

How smart meters will help us analyse our energy usage

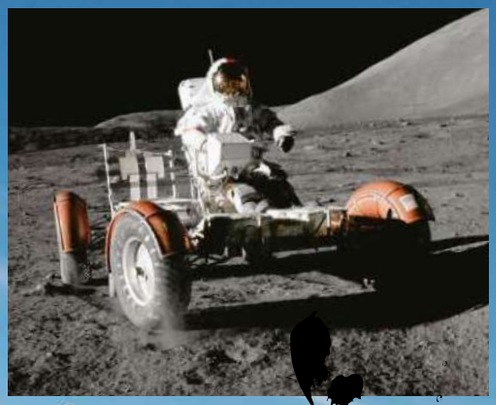


Smart hub communications
The hub is connected to a wireless network and takes constant readings of gas and electricity use.

In-home display
Customers can view their energy usage in close to real-time to check how much they're spending.

Sending information
The energy readings are sent to suppliers via secure wireless communications through the cloud.

More accurate bills
Homeowners will no longer have to rely on estimates but instead will have accurate and expected bill amounts.



EXTREME Off-Road VEHICLES

How these sturdy vehicles can conquer any terrain

FOUR-WHEEL DRIVES AND ALL-TERRAIN VEHICLES

Traditionally, cars are two-wheel drive. This means that only two wheels receive power from the engine at the same time — either the front or back set — and they are responsible for moving the car. They're suitable for roads and highways as they are lightweight and simple to construct, but they lack the ability to grip tougher terrain as two of the wheels are powerless and will get stuck on obstacles or slip on the ground.

The invention of the four-wheel drive (4WD) in the late 1800s pushed boundaries and successfully revolutionised the way we drive, letting us break free from the restriction of roads and giving us the freedom to roam almost any terrain. Modern 4WDs are designed to cross deserts, plough through snow and plunge into rivers, so we can explore our planet further than ever before.

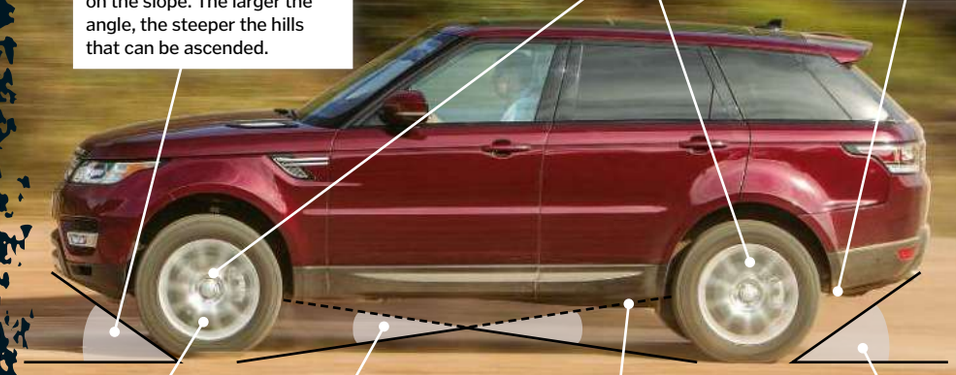
A successful off-road car is built on a robust and lightweight frame accompanied by large tyres with deep treads and tough sidewalls. Often, these tough vehicles are able to navigate difficult terrain as they've been built with an extra, very low gear — nicknamed the 'granny' gear — in addition to their long suspension that allows the car to almost bounce across rocks.

These cars are suitable for on the road and off the road, but for something more heavy-duty, all-terrain vehicles (ATVs) stand out as the unrivalled champion of tough terrain.

4WD cars are restricted due to the need to keep them as a high-performance vehicle on the road. This is where ATVs are able to excel in handling off-road. Also known as quad bikes or four-wheelers, they are incredibly versatile, small vehicles that operate like motorcycles and travel on large, low-pressure tyres and are equipped with handlebars for steering.

What makes an off-road vehicle?

Find out what a great off-road vehicle needs to tackle tough terrain



Approach angle
The approach angle determines the steepest hill that the vehicle can climb without touching the bumper on the slope. The larger the angle, the steeper the hills that can be ascended.

Axle articulation
Good articulation means that all four tyres are in contact with the ground, even when they're at different heights.

Skid plates
Plates fitted underneath the vehicle prevent important parts of the underbody, such as the fuel tank and exhaust, from hitting the ground.

Locking differentials
These physically lock the wheels together so they spin at the same speed and receive the same amount of power so that the wheels don't get stuck and stop moving.

Breakover angle
The breakover angle depends on both the approach and departure angles and describes the most the car can be tilted without the underbody touching the ground.

Ground clearance
As large a space as possible between the ground and the underneath of the car prevents damage from rocks and tree stumps hitting the underbody.

Departure angle
The departure angle is the maximum a vehicle can go down a slope without dragging the tail along the ground. The larger the angle, the steeper the hills that can be descended.

ATVs are typically operated like motorbikes but offer greater stability

Obstacles that would stop other cars in their tracks are no match for off-roaders

4x4 vehicles enable us to leave the roads behind and explore different landscapes

FORMULA OFF-ROAD

Formula Off-Road is a type of motor sport that combines precision driving, speed, steep hills, rocks, and water. The sport originated in Iceland but it's now popular in many Nordic countries and the US.

The events take place in areas that are closed with no traffic — often rock mines or craters as they offer an appropriately rocky terrain. There are tracks marked with sticks or flags and penalties for stopping, reversing the vehicle and driving a wheel on the markings of the track.

The drivers are protected with a roll cage, full-face helmet, neck support, five-point harness, flame-resistant clothing, shoes, gloves, and even arm restraints to prevent them from falling out of the vehicle. Each driver has a small team who prepare the vehicle and repair it throughout the competition.

Formula Off-Road sees competitors tackling extremely steep slopes

While dangerous, Formula Off-Road sees surprisingly few major accidents

"4x4s let us break free from the restriction of roads and give us the freedom to roam almost any terrain"

Q&A WITH A FORMULA OFF-ROAD DRIVER

We spoke to Arni Palsson about his years spent kicking up mud and speeding through the Icelandic craters in his modified Willys Jeep

Arni Palsson, born and raised in Iceland, took to Formula Off-Road as a teenager. Self-funded and with a car he modified himself, he quickly worked his way into the history of the sport. He raced full-time for over five years, winning several races and building a reputation for his fearless driving style.

When did you first get involved with the sport?

I had an old car and I thought I could do anything I wanted with it, so I built it up, changed the axles, got an engine. After I entered my first race I got more interested in the racing after that. I spent all of my money for many years on this sport. I bought the engine in the US. My uncle was a captain on a ship and he took the engine for me to Iceland so it would be cheaper. And after that I built it up with my friends, and they were always changing something to make it better: better axles, tyres, roll cages and so on.

How long did you race for?

I started racing in 1993 and my last race was in 1998. By the time I stopped the car was still very good, but unfortunately I had run out of money so I had to sell it!

What was your favourite aspect of the sport?

I loved everything, but especially when you were going fast in the race and you did something that impressed everyone and they cheered. My favourite moments were always when we were racing. It was a lot of hard work to build the car up, but when you were racing it was all worth it.

THE DAKAR RALLY

This infamous off-road endurance event pushes off-road engineering to its limits. The annual rally, organised by the Amaury Sport Organisation, was first held in 1978 and stretched 10,000 kilometres from Paris to Dakar in Senegal, taking about 16 days to complete. Since 2009, the race has been hosted by South America due to security risks in Mauritania.

Bikes, quads, cars, and trucks, both amateurs and professionals, enter the race, considered the most dangerous in the world. Drivers are at the mercy of nature, and since 1979, 70 people have died attempting to complete the race.

The Dakar Rally now journeys 8,000 kilometres through South America, incorporating the sands of the Atacama Desert and the heights of the Andes Mountains. It's split into 14 stages, some quite short and others up to 900 kilometres per day.

The drivers are pitted against one another in nature's toughest terrain, riding through its harshest weather conditions past a host of wild animals. Only the best drivers with the most capable off-road vehicles will cross the finish line.

The Dakar Rally is one of the most dangerous off-road events in the world

Motocross circuits can be on gravel, mud or grass

OFF-ROAD MOTORBIKES

Off-road motor bikes, also known as dirt bikes, are engineered to be lightweight and robust. They have a small engine (less than 500cc), making them agile and manoeuvrable, and are much simpler and lighter than their road-driving cousins. With little bodywork or frame covering their structure, suspension with extended forks to allow for jumps, rugged tyres, and very high ground clearance, dirt bikes make light work of almost any terrain.

The most popular form of off-road dirt bike racing is called Motocross. The first event of its kind was held in Camberley, Surrey in 1924. Motocross bikes are raced on short, closed, off-road tracks with obstacles including rivers. These bikes have a small fuel tank to keep them light and use long travel suspension so jumps can be taken at speed. Other types of popular off-road bikes include the Enduro, which is a modified dirt bike made road legal by a horn, lights and a number plate.

The biggest off-road races are the Dakar Rally, which will run through Peru, Bolivia and Argentina in 2018, and the Baja 1000 in Mexico's Baja California Peninsula.

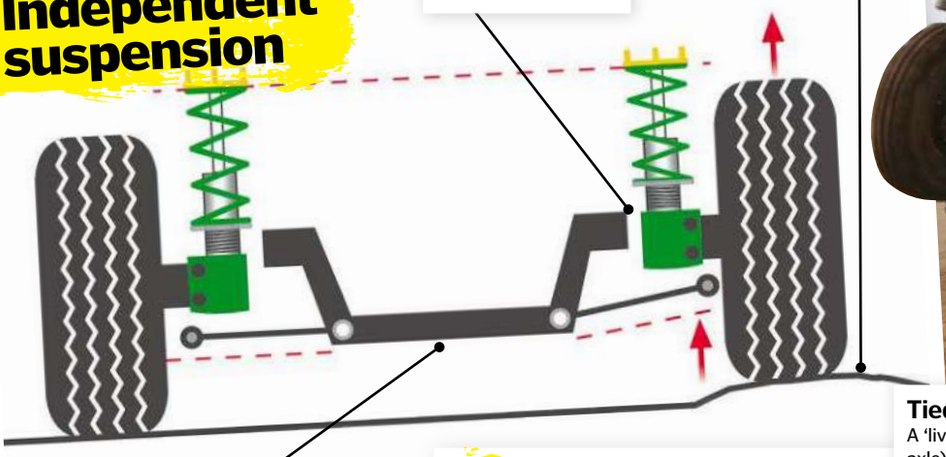
HOW DOES SUSPENSION WORK IN A 4X4?

The cost for a high-end off-road truck can reach beyond $500,000 (£387,000)

All vehicles rely on suspension for a comfortable ride because, both on the tarmac and on dirt tracks, we will encounter rocks, potholes and debris in our path. Without suspension a car would roughly jolt its passengers. The suspension gives movement to the wheels to keep the car more stable by using a system made from a spring and shock absorbers.

As the tyres of a moving car hit a bump in the road the tyres will be pushed up into the car and absorb the hit. The shock absorbers then work against the spring to dampen the movement and prevent the car from bouncing. Off-road cars predominantly use independent suspension systems as they provide better traction.

Independent suspension

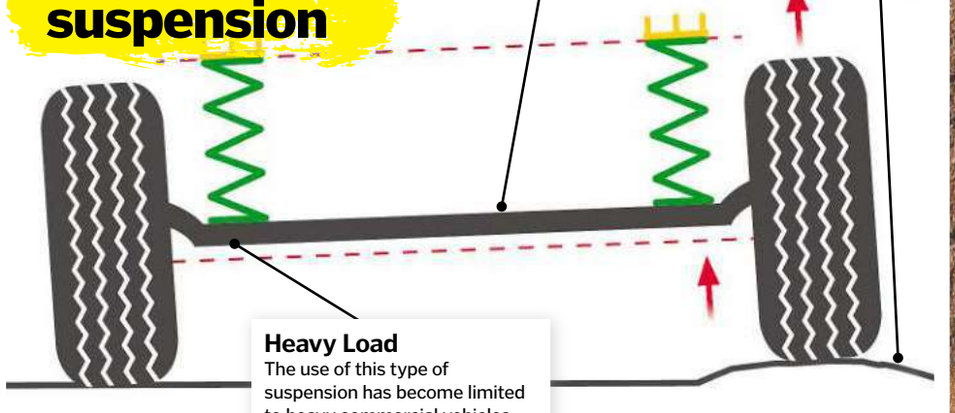


Swinging driveshafts
The movement between the wheels and differential is done by using swinging driveshafts connected by universal joints.

Hitting a bump
Each wheel on the same axle can move vertically without affecting the movement of the other wheels.

Freedom to move
The anti-roll bar ties the left and right suspension springs together but does not tie their movement together, so they are free to move independently.

Dependent suspension



Tied together
A 'live' axle (or de Dion axle) system fully links the wheels together.

Dependent movement
Movement on one side affects the wheel on the other side of the axle.

Heavy Load
The use of this type of suspension has become limited to heavy commercial vehicles, as it is impractical elsewhere.

"Only the best drivers with the most capable off-road vehicles will cross the finish line"

The lunar roving vehicle could reach a top speed of 13.8kph

OFF-ROAD, OFF PLANET

The Apollo lunar roving vehicle (LRV) was used on each of the last three Apollo missions to the Moon. Designed to traverse all terrain including slopes of up to 25 degrees, in temperatures that would range from -173 to over +118 degrees Celsius, this ultimate off-roader was an engineering marvel. This battery-powered, four-wheel open design vehicle could carry two astronauts, equipment and samples.

Developed in just 17 months, it was successful in assisting the astronauts on their scientific missions. With the help of the rovers, astronauts covered a greater area around their landing sites, driving distances of up to 36 kilometres across alien terrain. The three rovers remain on the lunar surface to this day.

"The lunar roving vehicle was the ultimate off-roader; an engineering marvel"

Low-gain antenna
Along with the high-gain antenna, this was used to transmit information, specifically voice and television camera data.

Central control panel and joystick
The rovers' 'dashboard' contained a joystick and a display console, which included a Sun shadow compass, a speedometer, an odometer and a pitch-angle meter.

High-gain antenna
This device transmitted images and data back to Earth.

Cargo
A storage area was used to carry scientific equipment and rock-sampling tools.

Electric power
Two 36-volt batteries were used to power the LRVs.

TV camera
The rovers also had on-board cameras that could be remotely operated from Earth.

Tyres
Supported by titanium treads, these featured two aluminum frames with a galvanised piano wire mesh.

The La Paz ropeway

The world's tallest urban cable car is revolutionising rush hour in Bolivia

Mi Teleferico is the highest ropeway of its kind in the world, towering over Bolivia's capital city at a dizzying 4,000 metres. When the first line was finished in 2014, connecting the urban centre of La Paz with El Alto in the Andes, it was the longest cable car system in the world.

The ropeway is a gondola lift design. The individual cars don't have acceleration or brakes — they simply grip to the cable, also known as the haulage rope. This is attached to a bullwheel driven by an electric motor, which rotates to shuttle the cars between stations. A cable car leaves the station every 12 seconds, and it takes just one kilowatt hour of electricity to transport three passengers, compared to 47 kilowatt hours for a minibus.

La Paz currently has four lines, with seven more planned. This should bring the carrying capacity up to 18,000 people an hour. The fifth line is due to open this October, and has been partly assembled by drone. The specially designed robots laid the guidewires to connect the stations for the new route, allowing heavier cables to be winched into place to build the final ropeway.

Minibuses on the ground expose their occupants to 9.6 parts per million (ppm) carbon monoxide, 1021ppm carbon dioxide and 68.3 decibels of noise. High above the city on the gondalas, the levels of carbon monoxide drop to zero, carbon dioxide falls to 312ppm and noise to 59.3 decibels.

Mi Teleferico is the tallest and longest urban cable car system in the world

What is land sailing?

Explaining the attraction of one of the world's most bizarre sports

Ostensibly an activity you'd expect to find nestled away in *Obscure Sports Quarterly*, land sailing is in actual fact a real pastime with its own advisory body and numerous clubs based around the UK. Essentially boats with three wheels and a sail, sailors lie down or sit and steer a T-bar (two pedals) with their feet. All the while the sail is operated by a rope, used primarily to control speed rather than direction.

Since these boats don't have the friction of the sea to slow them down, land sailboats are capable of reaching some seriously impressive speeds — the current record stands at 202.9 kilometres per hour!

King of the seven shores

The anatomy of a land sailboat

Sails
The sails are used for speed rather than steering.

Rope
Also called a line or sheet, this is used to manoeuvre the sail.

T-bar
The sailor uses their left foot to turn right and their right to turn left.

Piloting style
The occupant of the land sailboat either sits or lies down.

"Without the friction of the sea, land sailboats can reach seriously impressive speeds"

Highways to hell

Introducing the runways that will put you off flying forever

Kai Tak Airport
Hong Kong

Nicknamed the 'Kai Tak Heart Attack', it's perhaps a blessing for people's nerves that this no longer exists. Look to your right and you'd get a view into people's living rooms!

Courchevel Aiport
France

An uphill runway of just 537 metres that finishes with a terrifying vertical drop off the side of a mountain, this ski resort strip definitely isn't one for the faint-hearted.

Gibraltar
UK

Located right in the middle of the island's bustling city, this runway is just 1,680 metres long. It also intersects its busiest road, which is closed when a plane has to land.

Barra Airport
Scotland

Yes, that's really it — the airstrip is genuinely a length of sand rather than the tarmac we all know and love. Amazingly — or worryingly — this area isn't closed off to locals.

Kansai International
Japan

Seriously, just look at that view. We're sure the pilots know what they're doing and that this artificial island-set runway is perfectly safe, but from the sky this just looks utterly horrifying!

Inside the I-PACE

Jaguar's first all-electric road car that could give Tesla a run for its money

Perhaps the most eagerly anticipated car of the century, Jaguar's first all-electric car combines sports car performance with supercar aesthetics. The I-PACE Concept crossover SUV is expected to speed from 0-100 kilometres per hour in just four seconds by harnessing the power of two efficient motors installed at the front and rear axles.

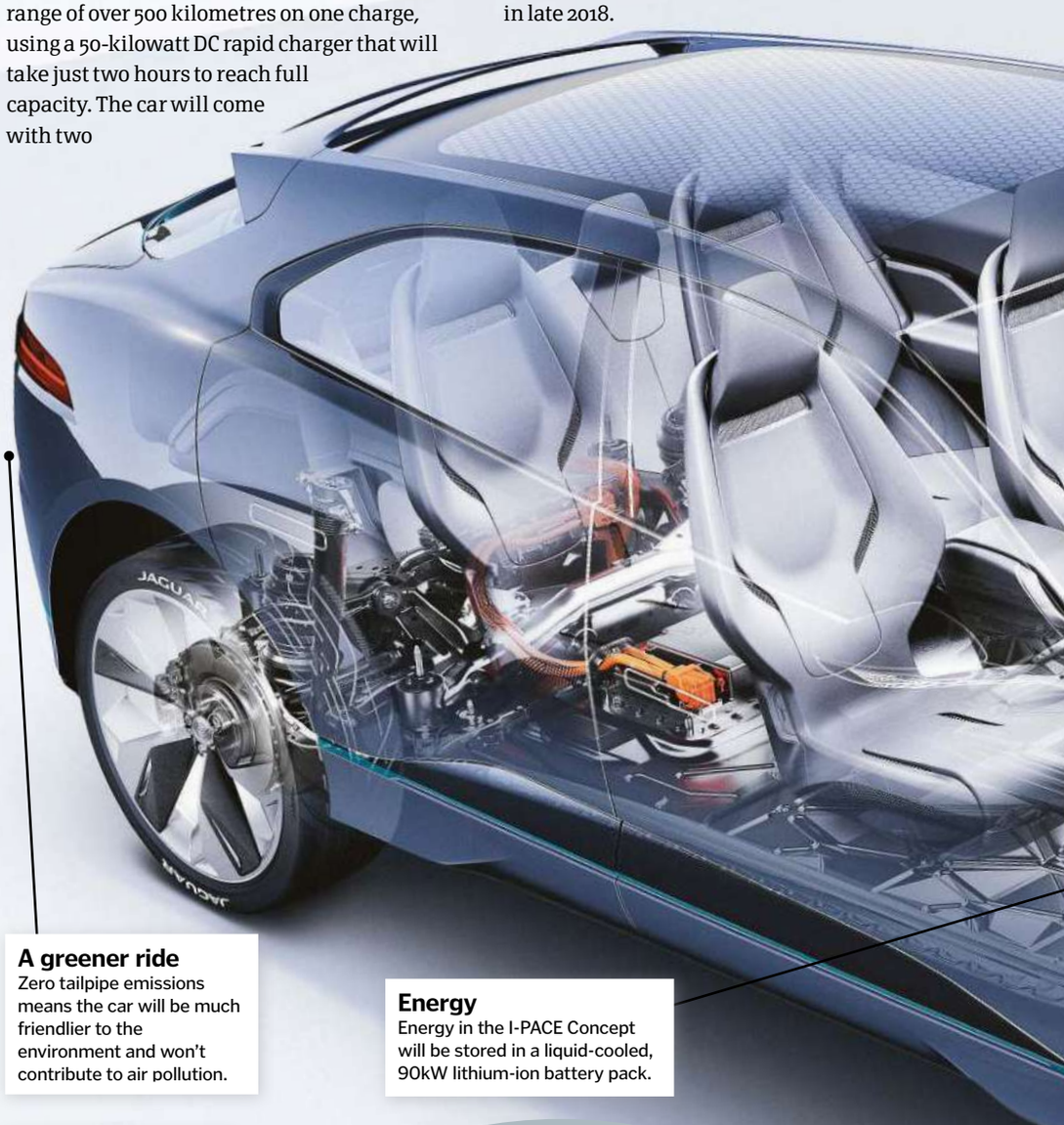
The absence of both an engine and a gear box means the car will be able to comfortably seat five in a spacious interior beneath an impressive full-length panoramic sunroof. The bold design and streamline silhouette creates a remarkably aerodynamic vehicle.

A rear spoiler will reduce lift and rear vents will channel air from the wheel arches into a smooth airflow behind the car to reduce drag, while the low centre of gravity makes for improved manoeuvrability and agility.

Electric cars provide a smoother driving experience. Ian Hoban, vehicle line director for Jaguar Land Rover, explains the benefits. "Electric motors provide immediate response with no lag, no gearshifts and no interruptions. Their superior torque delivery compared to internal combustion engines transforms the driving experience."

The I-PACE Concept is expected to have a range of over 500 kilometres on one charge, using a 50-kilowatt DC rapid charger that will take just two hours to reach full capacity. The car will come with two touchscreens in the centre of the dashboard, one to control information and entertainment functions and the other for the air conditioning and climate control.

With onboard Wi-Fi, the I-PACE is expected to be a blend of new technology and a polished aluminium and wood veneer interior. It is expected that the final production I-PACE will be seen by the end of this year, ready to go on sale in late 2018.



A greener ride
Zero tailpipe emissions means the car will be much friendlier to the environment and won't contribute to air pollution.

Energy
Energy in the I-PACE Concept will be stored in a liquid-cooled, 90kW lithium-ion battery pack.

Driver display
A high-resolution interactive driver display behind the wheel will replace the conventional speed and fuel gauges.

From Formula E to the I-PACE

The Formula E Championship is a class of racing that uses only electric cars. It encourages innovation through engineering and design by keeping standardised chassis and battery systems but allowing teams to compete with their own design of electric motor, control unit and transmission. The championship is run on street circuits in the world's biggest cities and challenges the power and performance of electric sports cars.

The I-TYPE is Panasonic Jaguar Racing's all-electric Formula E race car. It accelerates from 0-100 kilometres per hour in just 2.9 seconds, and is able to recycle up to 150kW of it's energy when it brakes to further extend its range.

The technical expertise and superb results from driving the Formula E have now been transferred over from the I-TYPE to the I-PACE. The new I-PACE will base its thermal management and motor location on its sports car predecessor as it continues to refine transferring power to the road efficiently.

Jaguar Racing's all-electric Formula E race car is the ultimate balance of power and efficiency

"Electric vehicles are inevitable – Jaguar will make them desirable. Zero-emission cars are here to stay, and the I-PACE Concept is at the cutting edge of the electric vehicle revolution"

Ian Hoban, vehicle line director, Jaguar Land Rover

Jaguar I-PACE technology

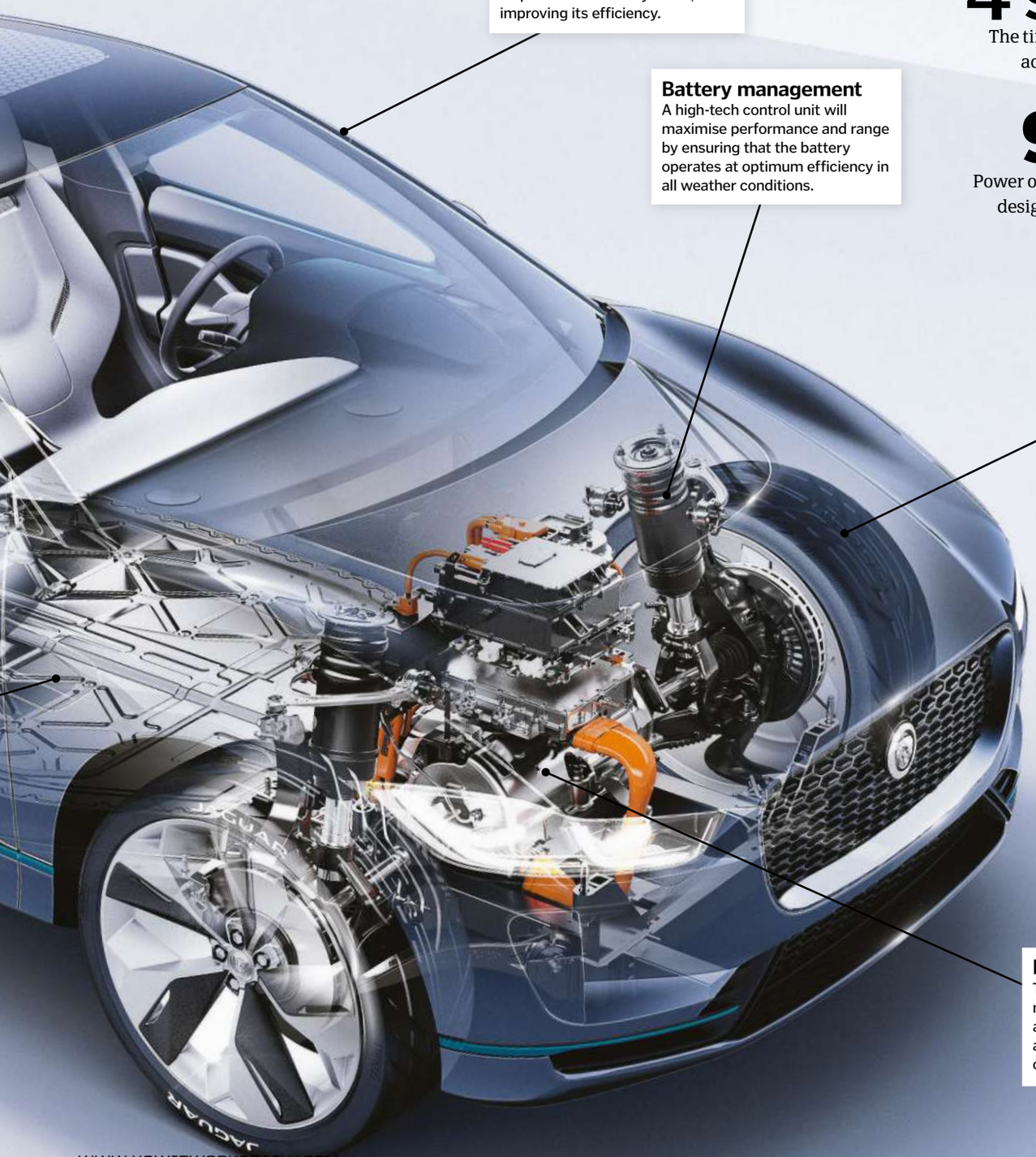
We go under the bonnet of the next big star on the electric car scene

Sleek design
The concept's sweeping bonnet, air ducts and flush door handles help to make it aerodynamic, improving its efficiency.

Battery management
A high-tech control unit will maximise performance and range by ensuring that the battery operates at optimum efficiency in all weather conditions.

Four-wheel drive
The I-PACE will have four-wheel drive capability for all-weather driving on any surface.

Power
Two efficient magnet motors will be installed at the front and rear axles to provide sports car acceleration.



500km
The distance the I-PACE will go on just one charge

90 minutes
The amount of time it will take for the car to charge to 80 per cent capacity.

4 seconds
The time it will take for the SUV to accelerate from 0-100kph.

90kW
Power of the lithium-ion battery pack designed by Jaguar Land Rover.

HISTORIC HEISTS

From crafty crooks to bumbling burglars, these heists had it all

If we're honest with ourselves, most of us dream of taking part in the perfect heist. Just as in Hollywood movies, in our fantasy we join a dedicated team of talented individuals. Each member harbours a secret talent that will help us crack a vault thought impregnable, and after we complete the perfect robbery we escape with our new fortune and the thrill of the event fresh in our minds.

Alas, for the vast majority of us, being part of Ocean's Eleven will forever remain just an exciting (highly illegal) thought. But throughout history there have been those that threw caution to the wind and either through ingenuity or stupidity have strived to achieve fortune in the most incredible ways. Some were successful. Many were not. But from each tale we can find the moments from which fictional stories have taken their inspiration.

From the bold Thomas Blood, who tried to steal the Crown Jewels by squashing the royal crown with a mallet, to the meticulously planned and executed Antwerp diamond heist, all manner of daring robberies have been attempted. In this feature we'll meet the people who thought they could replace stolen money with lottery winnings, resourceful scoundrels who dug epic tunnels into underground vaults, and senior citizens who pulled off heists most younger folk wouldn't dare to even think of.

When learning of the thieves' intellect and creativity (for the most part) in overcoming the challenges placed before them, it's easy to find ourselves whisked away by the tantalising sense of adventure and defiance of the odds. Read on to learn about their greatest ideas and biggest mistakes, and when you're next planning your own fantasy heist you'll know whether to escape in a powerboat or helicopter; whether to crack the vault door or drill through the wall; and whether playing a board game straight after a heist is a good or a bad idea.

The Great Train Robbery of 1963

A notoriously bold and skilful heist that was foiled by a board game

After emerging from prison in 1962, Bruce Reynolds, along with a few of his close accomplices, began to devise a daring plan. They sought to steal from a post office train packed with registered mail, which almost always contained cash. And to make this potential hit even sweeter, the team was advised to strike after a bank holiday.

Reynolds and the South West Gang of London allied themselves with the South East Gang, and the team quickly set about planning and executing one of the most notorious heists in history. Relying on an inside man known as the 'Ulsterman', the robbers knew exactly which train to stop and when to do it. Their plan to halt the train with a stop signal worked, but with the heist in full swing the robbers hit a major snag.

One member of the team, known as 'Peter', had spent several months learning about the mechanics of driving a train from railway staff under the guise of being a railway enthusiast. Confident that he could move the train, his belief evaporated as he confronted a huge diesel engine quite at odds with the smaller trains he'd been handling. The team had to coerce the train's driver to move them forwards.

After the money had been transferred to their getaway cars the robbers retreated to a hideout. They'd stolen £2.6 million (£30 million today) in a matter of minutes without the use of guns or excessive force, but their plan soon to fell apart.

The first blunder came from a gang member who told the train staff to wait for 30 minutes before calling the police, which revealed a key clue: their hideout must be nearby. That, coupled with the fingerprints left at the hideout after the men had been playing *Monopoly*, was to seal the robber's fate. The police soon rounded up the majority of the members involved.

End of the line

How a group of daring thieves pulled off the near-perfect heist

1 Planning

The gang wanted to hijack a Travelling Post Office train heading from Glasgow to London. Their target was the second carriage from the front – the High Value Package carriage. They needed to map the train's journey to make sure they were ready and waiting when it arrived.

2 Stop signal

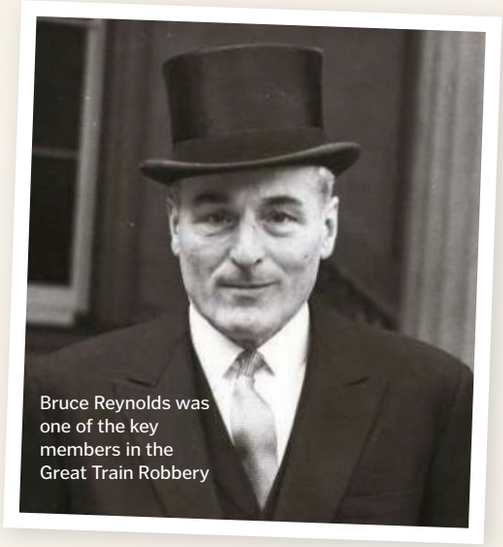
At around 3am, as the train approached their location, some of the gang members engaged a stop signal, forcing the train to a halt. They managed to block the 'Go' signal (a green light) using simple leather gloves, and a six-volt battery was used to activate the red 'Stop' light.

3 All aboard

The gang boarded the train, uncoupled the carriages that weren't needed and convinced the driver to continue for another mile to Bridego Bridge, where the rest of the robbers were waiting. The team formed a human chain and unloaded 120 sacks in 15 minutes into getaway vehicles.

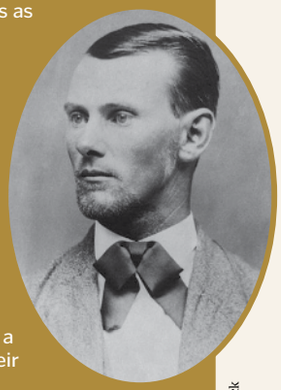
4 Laying low

The robbers drove back to their hideout, a rented farm stuffed with provisions, sleeping bags and bedding. They passed the time playing *Monopoly*, leaving behind their fingerprints. They fled the farm shortly after, but the police soon acquired this incriminating evidence.



Bruce Reynolds was one of the key members in the Great Train Robbery

Jesse James: train robber extraordinaire



Few villains are as infamous as Jesse James and his gang. Initially frequent raiders of banks, the thieves later turned their attention to trains. But as with all new ventures, there was a steep learning curve to their effectiveness.

For their first train heist, the gang decided that stopping the train would be much simpler than chasing it on horseback. They tore away a section of track to force their target to a standstill, but unfortunately their work caused the front of the train to topple over. Afterwards, they used a tactic similar to the one used during the Great Train Robbery almost 100 years later: they'd stand on the tracks and stop the trains by simply waving a warning light.

Bank heists

The criminals that bested some of the world's top security

Top tips for a successful robbery*

Have the right tools

There's nothing more frustrating than reaching a bank vault wall and realising you've brought the wrong drill. Make sure you have what you need.

Disguise yourself

In an age of CCTV and witness statements, you'll want to hide your face during a heist. A disguise will help throw the authorities off your tail.

Plan carefully

All successful heists are well planned. If you're digging a tunnel into a bank, you want to make sure you drill into the vault and not into the security office.

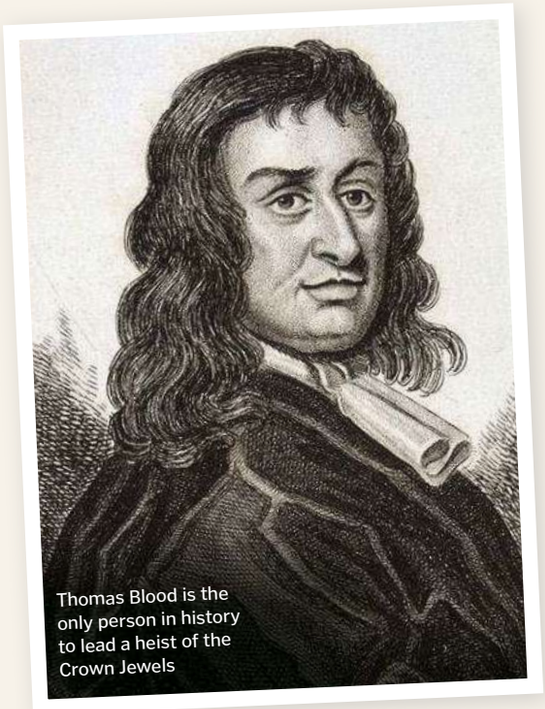
Use a fake name

Like the robbers who posed as Paddy One, Two and Three and spoke in fake Irish accents, you're going to want to hide your real identity from any witnesses.

Bring an expert

Many heists fail because they don't use a professional. Use a skilled engineer for digging tunnels and an experienced driver for your quick getaway.

*Neither Future Publishing Ltd nor any of its employees or representatives in any way advocate or endorse the commission of any criminal offences of any nature.



Thomas Blood is the only person in history to lead a heist of the Crown Jewels

Fortaleza Central Bank

The robbers dug a sophisticated tunnel to gain access to the bank's vault

Documented as the greatest bank robbery of all time, a gang of thieves made history in 2005 when they stole from the Banco Central in Fortaleza, northeast Brazil. While posing as a landscaping company, the group paid for a nearby building and got to work digging an 80-metre-long tunnel to the bank's underground vault. To be as efficient as possible, they reinforced the dug walls with wooden panels, fitted electric lighting and even added basic air-conditioning. And to make sure that the locals didn't grow suspicious, they handed out promotional merchandise and advertisements for their fake landscaping business.

Upon reaching the vault walls, the robbers drilled through over a metre of steel-reinforced concrete to get access to the money. Inside, cash in the form of old notes that had been removed from circulation and new notes ready to be released into circulation sat waiting for them. The gang left the new notes and escaped with almost £40 million in old notes, as the bank had kept no trace of their serial numbers.

The safety deposit boxes in Knightsbridge vault held items worth millions

Knightsbridge vault

Valerio Viccei was a strong believer in living dangerously. An enthusiast for all manner of unsavoury activities, it was only natural that he would attempt to steal from London's richest after migrating to the UK in 1986. In his native Italy he was wanted for 50 armed robberies.

Alongside an accomplice, Viccei targeted London's Knightsbridge vault, which held a collection of security deposit boxes. After entering the building and asking to rent a deposit box, he subdued the manager and guards once inside the vault. To avoid discovery, he hung a sign up informing customers the vault was closed. He escaped with a haul worth £60 million and left the UK but was later caught when he returned to collect his Ferrari.

Stealing the Crown Jewels

In 1671, a rogue Irishman named Thomas Blood hatched a plan to steal the King of England's Crown Jewels, a feat that would cement his place in crime history.

Entering the Tower of London disguised as a member of the clergy, Blood formed a friendly relationship with the Keeper of the Jewels, Talbot Edwards. After several visits, he returned with a small group of men and Edwards agreed to show them the King's treasures. But after unlocking the door to the room where they were kept, he was knocked unconscious.

Blood seized the royal orb and stuffed it down his breeches, and to make sure the crown would fit in his bag, he squashed it with a mallet! The men were caught as they tried to leave the Tower, but when taken before the king, Blood impressed him with his bold confidence so much that not only did he grant a full pardon, but he also rewarded Blood with land in Ireland!

A number's game

If there was ever a robbery that relied on the favouritism of lady luck, this was it. Two Chinese bank workers had grown tired with their low-paid jobs and sought to steal from their employer and replace their takings with lottery winnings.

Incredibly, their first attempt at stealing money to invest in lottery tickets actually worked. The robbers replaced what they had stolen using their winnings and kept the difference.

Unfortunately, greed was their undoing, and after stealing considerably more for their next endeavour – roughly £5.3 million – the men found that luck had abandoned them and they were unable to find a winning ticket. What had seemed like a fool-proof plan quickly dissolved, and the bank soon discovered the missing funds and arrested the parties involved. The two unlucky workers were sentenced to death.

The hole drilled into the Hatton Garden vault wall was just large enough for the thieves to fit through

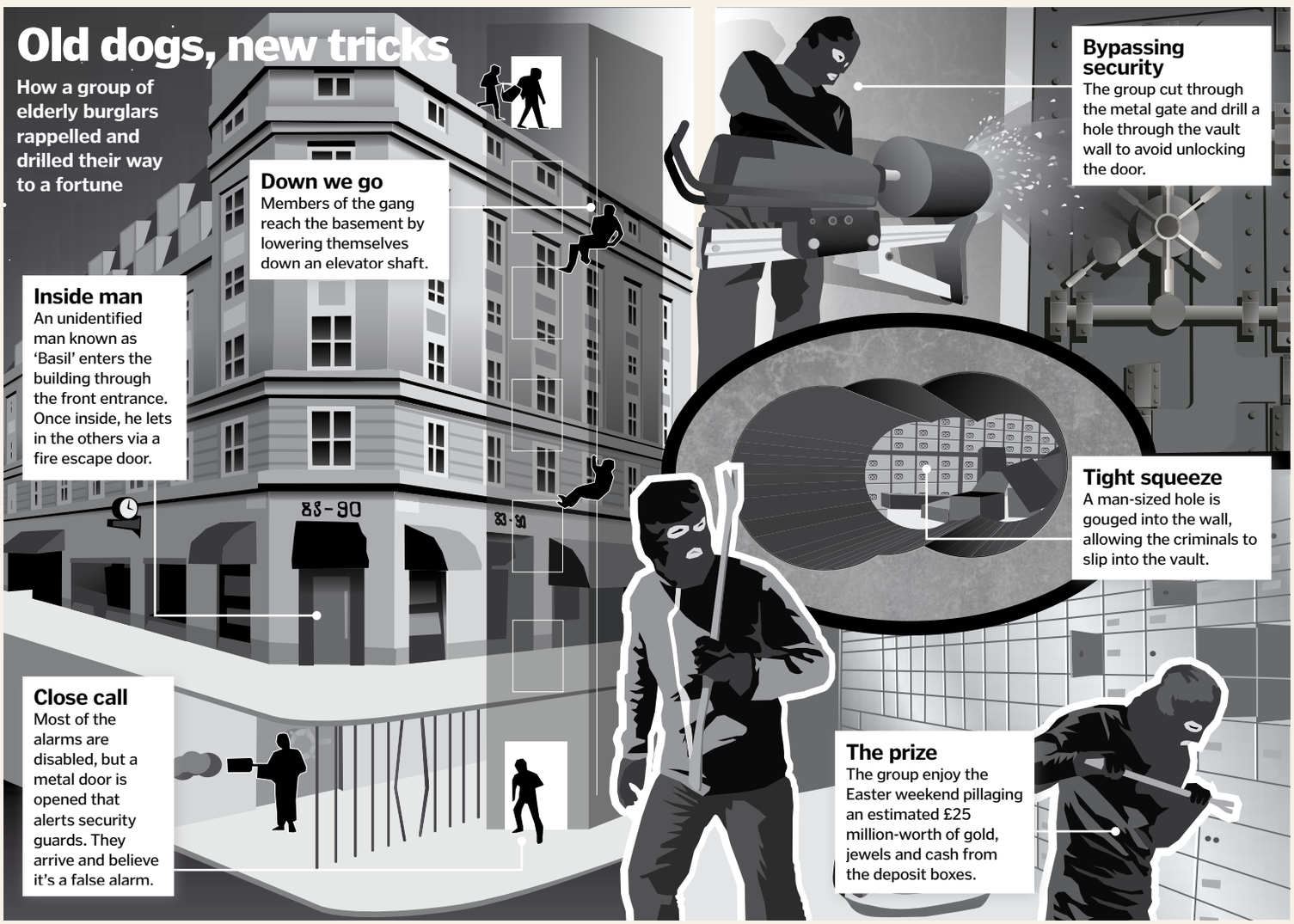
Hatton Garden

The thieves that made the 2015 Easter weekend a holiday to remember

In April 2015, the Hatton Garden Safe Deposit Company premises hosted a group of uninvited visitors. Just before the building closed for the bank holiday, an inside man smuggled his accomplices in, and after security headed home, the experienced criminals got to work.

The media were surprised to discover that the heist hadn't been pulled off by young crooks but senior citizens. Brian Reader was the oldest member at 76; Carl Wood was the youngest at 59.

When sneaking down the elevator shaft, disabling security and drilling and cutting through steel and concrete, the team put their experience to good use. They were almost caught when they triggered an alarm, but afterwards the team was free to spend the weekend raiding. They didn't leave a single fingerprint but were undone by their traceable mobile phones and one member's internet search history, which revealed the planning.



The crime of the century

Uncover the jewel of the robbery world: the Antwerp diamond heist

The Antwerp diamond heist is one of the most famous criminal acts for a multitude of reasons, with the value of the goods stolen, the sheer complexity of the obstacles overcome, and the intriguing nicknames adopted by the thieves being just some of the more notable aspects.

The leader of the team that pulled off a robbery with similar grandeur to a Hollywood film was Leonardo Notarbartolo, a charming Italian man with strong links to the Sicilian Mafia. He was already an accomplished diamond thief and had a rented office in Antwerp – the nexus of the world's diamond trade – to sell and trade his stolen goods. He put this familiarity to good use when he began to scout the Antwerp Diamond Centre, as he was able to sweep passed security and peruse the vault itself.

This inside access proved immensely valuable for the planning to come. The Diamond Centre's vault was believed to be an impregnable fortress, and many of the city's wealthiest rented safety deposit boxes there for a secure place to stash their valuables. Cash, gold bars and of course plenty of diamonds were bound to be found inside. Leonardo realised that it would be a tough challenge to get to them. He would need a crack team to be able to do it.

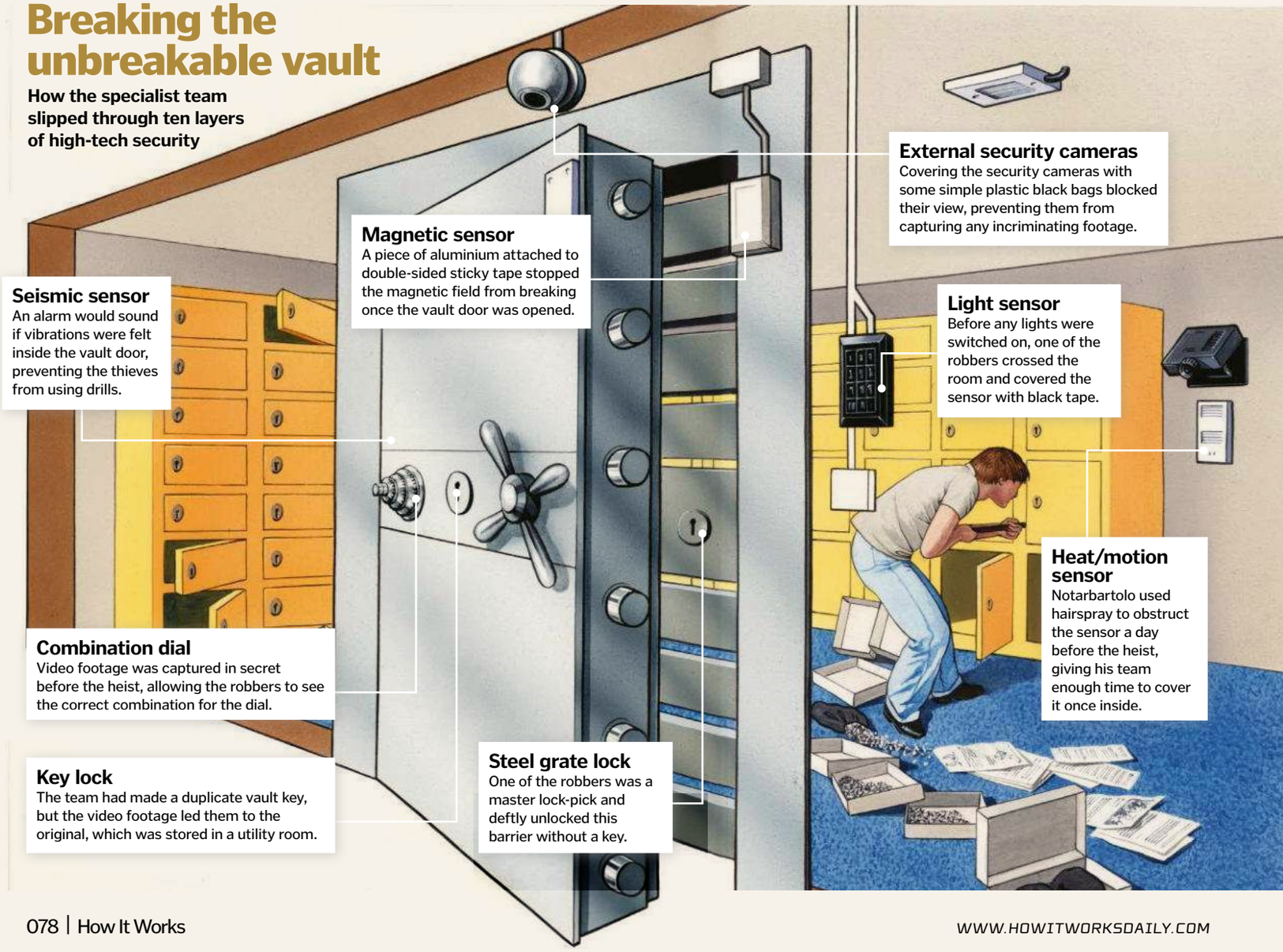
Enter the experts, who have always been described by Notarbartolo by their mysterious nicknames: The Genius, The Monster and The King of Keys. Together, the three of them practised their outrageously ambitious plan inside a replica vault, while Leonardo continued to gather vital intelligence and plant video cameras inside the building.

In February 2003 the team raided the heavily protected vault without sounding a single alarm. The three experts entered the building through a window while 'Speedy' – one of Notarbartolo's long-serving accomplices – waited in the getaway vehicle with a police scanner. Over 100 boxes were forced open and the men collected contents worth up to $100 million in duffel bags. As the Sun rose over the city, the loot was divided and the team left for Milan.

During the journey, Leonardo and Speedy pulled off the highway to discard incriminating evidence, such as receipts and contact details for the other members. They cast them into the forest thinking no one would ever find them. Unfortunately for them, the evidence was swiftly found by the landowner, and all but The King of Keys were soon identified and convicted.

Breaking the unbreakable vault

How the specialist team slipped through ten layers of high-tech security



External security cameras
Covering the security cameras with some simple plastic black bags blocked their view, preventing them from capturing any incriminating footage.

Magnetic sensor
A piece of aluminium attached to double-sided sticky tape stopped the magnetic field from breaking once the vault door was opened.

Seismic sensor
An alarm would sound if vibrations were felt inside the vault door, preventing the thieves from using drills.

Light sensor
Before any lights were switched on, one of the robbers crossed the room and covered the sensor with black tape.

Heat/motion sensor
Notarbartolo used hairspray to obstruct the sensor a day before the heist, giving his team enough time to cover it once inside.

Combination dial
Video footage was captured in secret before the heist, allowing the robbers to see the correct combination for the dial.

Steel grate lock
One of the robbers was a master lock-pick and deftly unlocked this barrier without a key.

Key lock
The team had made a duplicate vault key, but the video footage led them to the original, which was stored in a utility room.

Mission improbable

Diggers, disguises and powerboats, the Millennium Dome raid had them all

As the year 2000 began, a motley crew of sinister characters from London, Kent and East Sussex set their sights on a diamond display at the Millennium Dome worth an estimated £350 million. The centrepiece of this collection was the Millennium Star, regarded as one of the world's most perfect gems.

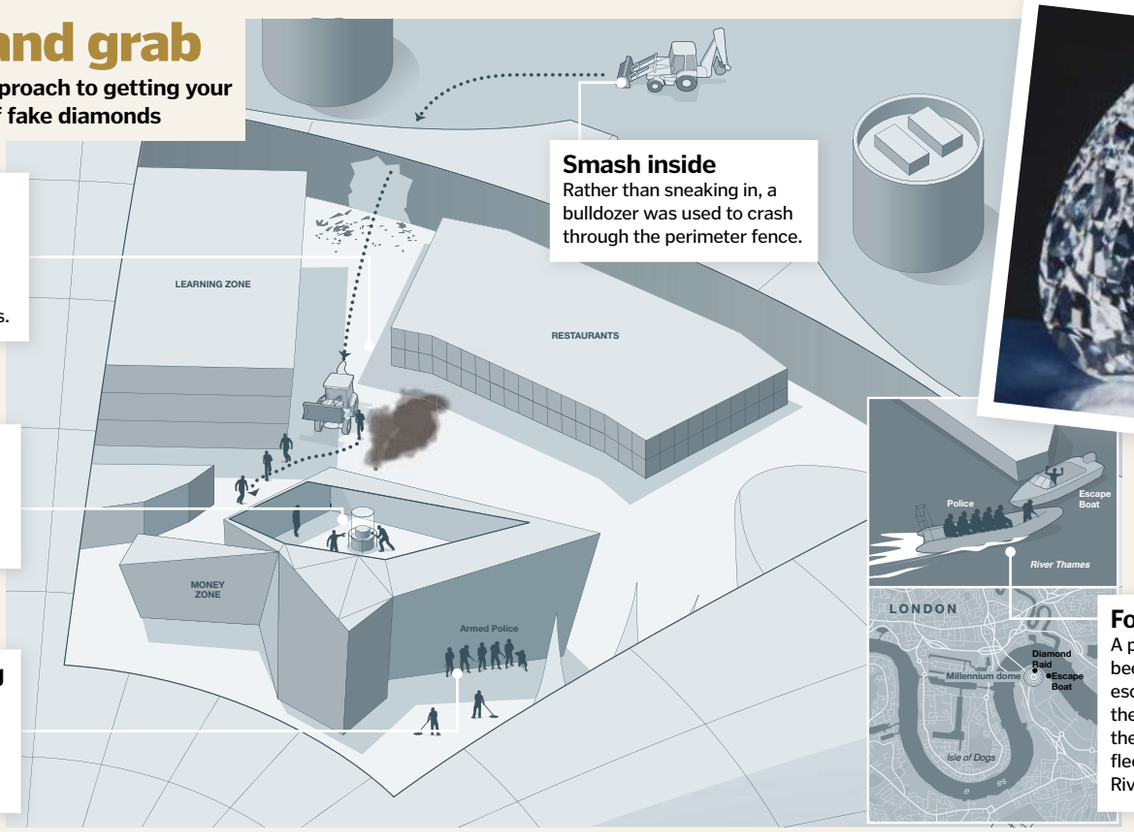
Rather than adopting a covert approach favoured by many successful burglars before them, the group decided on formulating a more straightforward plan around a bulldozer, smoke grenades, sledgehammers and a powerboat.

Their unbelievable lack of subtlety soon attracted the attention of the police, who quickly realised that a smash-and-grab raid was being planned and who was involved.

The robbery was doomed to fail before it had begun – the police had already swapped the diamonds with replicas and were ready and waiting on the day of the heist to catch the raiders in the act.

Smash and grab

The brute force approach to getting your hands on a heap of fake diamonds



Clear the area

While wearing gas masks, the raiders launched smoke grenades to disperse the crowds and guards.

Smash inside

Rather than sneaking in, a bulldozer was used to crash through the perimeter fence.

Grab the goods

The gang tried to free the diamonds with a sledgehammer and a nail gun.

Police in waiting

Law enforcement had been expecting the raid and were on site to subdue and arrest the robbers.

Foiled escape

A powerboat had been chosen as an escape vehicle, but the police prevented the gang from fleeing down the River Thames.

Creative crooks

Discover some of the quirkiest heist tactics ever used

Escape via helicopter

In 2009, a cash depot in Stockholm was the victim of an audacious heist. Before the robbers took the money they blocked the doors and lined the streets with spiked objects. Their planned escape route? A stolen helicopter hovering above the roof of the building. Spectacularly, their plan worked.

Use Craigslist

A man who robbed an armoured truck in Monroe, Washington, employed a devious approach to lose his pursuers. Wearing a yellow vest, blue shirt and a respirator mask, he fled into a crowd of men dressed in the same attire. He had lured the doppelgängers there with an online advert offering maintenance work.

Parachute

Championed by the famous D B Cooper and emulated afterwards by many copycats, these criminals took airplanes and their crew hostage. From the runway they demanded money and parachutes, and once their demands were met they commanded the pilot to take to the skies. Once they were at a low altitude the hijackers leapt from the plane.

Police imposters

The power of costumes should never be underestimated, as members of security at the Isabella Stewart Gardner Museum found out in 1990. Two thieves dressed as police officers convinced security they were responding to a call, then handcuffed them and escaped with art worth $500 million.

Distract with smoke

In 1968, a bank car in Japan was carrying 300 million yen when it was stopped by a man in uniform. He told the team inside that their car was the target of a bomb threat, and as he checked under the vehicle smoke billowed out. The team fled while the man stole the vehicle, leaving his smoke bomb behind.

Incognit-OAP

When most people would be settling into retirement, the so-called 'Geezer Bandit' decided to begin a new venture: robbing banks. Starting in 2009, the pensioner has successfully robbed at least 16 banks in Southern California by approaching the teller with a pistol and a note demanding cash. But is the old man look just a clever disguise?

The corvus

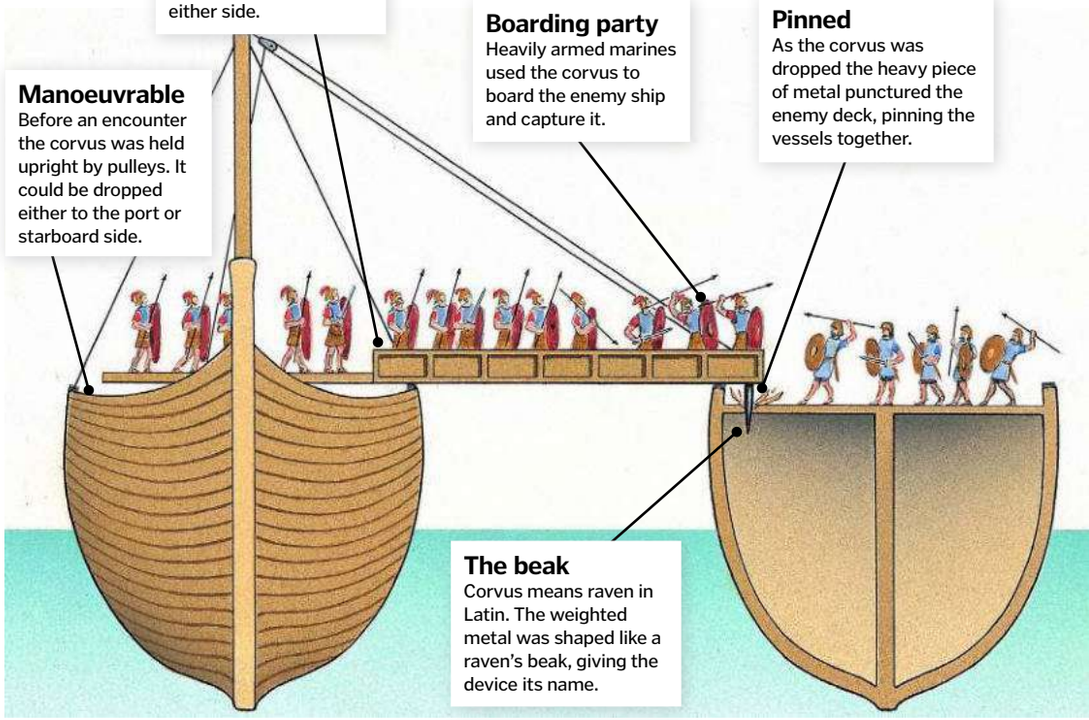
The invention that turned the tide for the Romans during their first war at sea

As the Carthaginians approached the Roman fleet near Mylae in 260 BCE, they saw an unfamiliar object affixed to the prow of the opposing ships. The marines were startled, but as their ships were both faster and better constructed they continued their advance full of confidence. What followed would be remembered as a great victory for the Romans and a disaster for their adversaries.

A common tactic in ancient naval warfare was ramming and sinking enemy ships, but the Romans knew they were outclassed in a typical sea battle. Instead, they favoured boarding the enemy ships with their superior soldiers, and so they designed the corvus. They put the new invention into practice at Mylae. When their opponent's vessel neared they dropped their new boarding bridge onto their decks, pinning them and enabling Roman marines to swarm aboard and take the enemy ship.

All aboard

How the Romans brought hand-to-hand combat to naval battles



Automatic doors of the ancient world

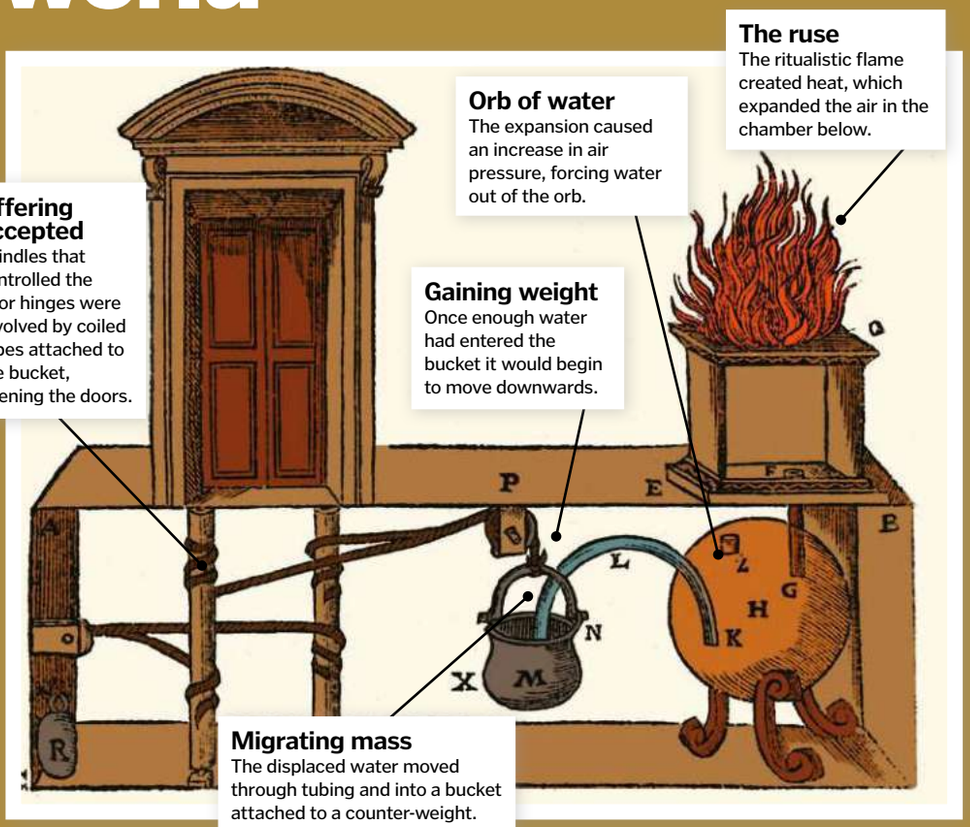
A bright spark called Hero of Alexandria designed the world's first self-opening temple doors

As worshippers gathered around a temple of the ancient world they were treated to a sight so spectacular that it appeared to prove the existence of the gods. The congregation would watch as a temple priest stood beside a set of grand entrance doors and lit a large fire to begin his ritual. He would then make an offering over the flames, and after some time the doors would open wide, seemingly by the gods themselves.

But what looked to the crowd as divine intervention was in fact an advanced mechanism working beneath the temple's surface. It had been designed by Hero of Alexandria, a famous inventor whose knowledge of physics far exceeded that of his contemporaries. Hero understood that air could be pushed and pulled, and it was by exploiting this knowledge that he designed one of the greatest illusions of power in the ancient world.

Hero's automata

Explore the mechanics that created an illusion of magic



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Alchemy

The ancient practice of trying to turn lead into gold was the protoscience that gave birth to modern chemistry

The origin of alchemy lies in ancient Egypt, where the cultures of the ancient Greeks and Arabs melded together and the first alchemists began by making glass, medicines and metals. They wanted to understand the secrets of the world around them and were searching for the 'prima materia', the matter from which all other matter was created. Sulphur, mercury and salt were considered to be the three 'heavenly substances'.

In the 14th century, Spanish alchemist Geber helped to spread alchemy across Renaissance Europe. He believed that all metals were made from mercury and sulphur and that copper, lead, iron, silver and tin could all be transformed into gold with the help of the philosopher's stone – a concept known as chrysopoeia.

This, along with the elixir of life, was the major focus of alchemy, but behind the myth and magic was some real science. Geber learned to make stronger acids by distilling vinegar to drive off the excess water; Swiss-German alchemist Paracelsus (born Theophrastus von Hohenheim) invented an opium painkiller called laudanum; and in 1669, German alchemist Hennig Brand (depicted below) boiled urine and discovered a white material that glowed green in the dark: phosphorous.

Alchemists in China and India had also been experimenting, inventing black powder, forging steel and discovering that flames changed colour depending on which metal was burnt. But in 1661 alchemy started to change.

Irish alchemist Robert Boyle published a book titled *The Sceptical Chymist* that called for a more scientific approach to their work, and after decades of study chemistry finally started to appear in its modern form. In the 19th century, French chemist Antoine Lavoisier laid down the theory of the conservation of mass, explaining that matter cannot be created or destroyed and debunking alchemical myths once and for all.

Physicist or alchemist?

Sir Isaac Newton is best known as the genius physicist and mathematician behind the law of universal gravitation, the laws of motion, calculus and the reflecting telescope, but this great scientist was also an alchemist. In fact he wrote more about alchemy than he did about any other subject. But in the 1700s alchemy was taboo and his work on the subject was buried after he died.

In 2016, a closer look at his writings revealed hints that he was working on the fabled philosopher's stone. Alchemists thought that this object would turn cheap metals into gold and might also hold the secret to eternal life. Within Newton's manuscripts is a recipe for one of the key ingredients, philosophic mercury, and historians think that it's likely he tried to make it as part of his experiments.

There are hundreds more pages of Newton's writings just waiting to be explored

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BRAIN DUMP

Because enquiring minds need to know...

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MEET THE EXPERTS

Who's answering your questions this month?

Laura Mears

Laura studied biomedical science at King's College London and has a master's from Cambridge. She escaped the lab to pursue a career in science communication and also develops educational video games.

Alexandra Cheung

Having earned degrees from the University of Nottingham and Imperial College London, Alex has worked at many prestigious institutions, including CERN, London's Science Museum and the Institute of Physics.

Tom Lean

Tom is a historian of science at the British Library where he works on oral history projects. He recently published his first book, *Electronic Dreams: How 1980s Britain Learned To Love The Home Computer.*

Katy Sheen

Katy studied genetics at university and is a former **How It Works** team member. She now works for a biomedical journal, where she enjoys learning about the brilliant and bizarre science of the human body.

Joanna Stass

Having been a writer and editor for a number of years, **How It Works** alumnus Jo has picked up plenty of fascinating facts. She is particularly interested in natural world wonders, innovations in technology and adorable animals.

Lemurs at the Smithsonian Institution's National Zoo began calling loudly minutes before a quake in 2011

Can animals tell when an earthquake is about to happen?

Travis Jonson

There are plenty of anecdotes supporting this theory, including chickens that stop laying eggs, bees fleeing their hives and dogs howling in the days or weeks leading up to a quake. However, animal behaviour is influenced by many different factors and no research has been able to confidently say that creatures can sense quakes in advance. On the other hand, some animals can feel earthquakes a few seconds before us due to their ability to detect the fastest types of seismic waves. This may explain why animals seem spooked before the first tremor hits. **KS**

What is the Resolute desk?

Felix Jones

For over 130 years, the Resolute desk has been used by presidents of the United States, either in the Oval Office or the White House Residence. It is constructed from timbers of the HMS Resolute, an abandoned British vessel that was discovered by an American ship and returned to Queen Victoria. As a token of her gratitude, Queen Victoria commissioned the desk and presented it to President Rutherford Hayes in 1880. **KS**

How does Google's search engine work?

The Google Search Index is well over 100 million gigabytes in size

Rachel George

When you Google something, you're not actually searching the internet, just Google's index of it. Software programs called spiders crawl around the web gathering information from billions of webpages and organise them in Google's Search Index. When you search, algorithms analyse the words in your query and look for every page in the index that mentions them. They then analyse those pages to work out how useful they are and determine their PageRank, a formula that rates a page's importance by looking at how many other pages link to it. Each page is then given an overall score to determine the order of your search results. **JS**

What defines a 'world' war?

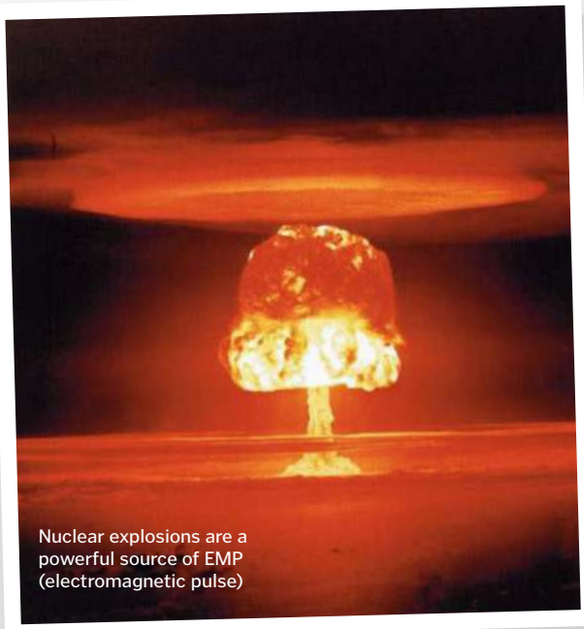
Lucia Mares

A world war can be defined as a war involving many nations in all different parts of the world, but there are no specific guidelines on how many nations must be involved. The First World War was given its name in 1918 by British war correspondent Charles à Court Repington and military historian Major Johnstone to "prevent the millennium folk from forgetting that the history of the world was the history of war" and warn them that a second could occur. **JS**

What is an EMP (electromagnetic pulse)?

Colin Battersea

An EMP is a short burst of electromagnetic energy, which could be either caused naturally, such as by a lightning strike or a solar flare, or by a human-made device, such as a nuclear bomb exploding. The electromagnetic pulse includes electric and magnetic fields that can induce electrical currents in the circuits of electronic equipment. This can disrupt them temporarily or even burn out and destroy the circuits if the current is powerful enough. **TL**



Nuclear explosions are a powerful source of EMP (electromagnetic pulse)

What do the Gs mean in 3G and 4G?

3G is 'third generation' and 4G is 'fourth generation', and the main difference comes down to speed. As mobile networks have improved, download speeds have jumped from 3Mbps to around 40Mbps. **LM**

Are birds warm-blooded or cold-blooded?

All birds are warm-blooded, which means they can regulate their own body temperature. However, some birds migrate during the winter season to avoid extremely cold climates. **KS**

Why is mercury used in thermometers?

Mercury is liquid at room temperature and its volume expands significantly and consistently with increases in temperature, making it suited to use in a thermometer. **AC**

What is the difference between mass and weight?

An object's mass is the quantity of matter it contains. Its weight is the gravitational pull exerted on it. While mass is constant, weight can change based on location. For example, the same object would weigh more on Earth than on the surface of the Moon, but its mass remains unchanged. **AC**

BRAIN DUMP

Hydrogen accounts for roughly 73 per cent of the universe's matter today

Why is hydrogen so common in the universe?

Alan O'Connell

As the simplest element (with just one proton in its nucleus), hydrogen was produced in vast quantities in the early universe and has dominated ever since. Protons and neutrons appeared one second after the Big Bang. Pairs of protons and neutrons combined to form deuterium nuclei, which fused to create helium nuclei. But the abundance of protons relative to neutrons meant that single protons (in other words hydrogen nuclei) outnumbered helium nuclei and the early universe ended up consisting of roughly 75 per cent hydrogen and 25 per cent helium atoms by mass. Other elements were created much later when hydrogen and helium fused inside stars. **AC**

Cure brain freeze by pressing your tongue to the roof of your mouth

What is 'brain freeze' and why does it hurt so much?

Verity Lavigne

Two really important sets of blood vessels run close to the roof of your mouth: the interior carotid artery, which feeds the whole brain, and the anterior cerebral artery, which supplies blood to the front of your brain. If you eat something cold really quickly, the temperature shock causes these blood vessels to narrow. To prevent a loss of blood to your head, they then quickly widen again, causing a sudden, painful increase in blood flow. **LM**

Who was the first Egyptian Pharaoh?

The first true pharaoh was Narmer. He united Upper and Lower Egypt through conquest to become the first ruler of the First Dynasty in 3150 BCE. **JS**

Which of Henry VIII's wives was he married to for the longest?

Henry VIII's first marriage to Catherine of Aragon lasted 24 years, 14 years longer than the rest of his marriages combined. Their divorce in 1533 led to the establishment of the Church of England. **JS**

There are gas planets, so why no gas moons?

Gas planets have a small, rocky core surrounded by liquids and gasses. Gravity holds gas planets together by stopping the gasses escaping. Moons are comparatively small so have weak gravity. It's hard for them to hold on to an atmosphere, making a gas moon unlikely. **TL**

What exactly are solitary bees?

Unlike bumblebees and honeybees, which live together in colonies, most species of bee are solitary. Solitary bees make individual nests and live independently, but they are still very important for pollinating plants. **TL**

The higher you climb, the less energy it takes to make water boil

Why do boiling points change with altitude?

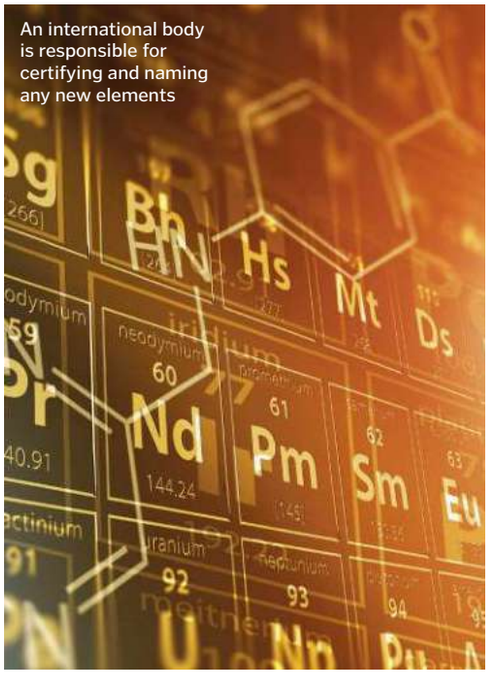
Beate Johannsen

The boiling point of a liquid is related to something called vapour pressure. If you put the liquid inside a closed container, some of the molecules will evaporate, pushing against the surface. The higher the temperature, the more liquid turns to vapour and the higher the pressure becomes. When vapour pressure gets high enough to equal atmospheric pressure (760 mmHg at sea level), the liquid starts to boil. The temperature needed to make this happen is known as the boiling point. If you climb a mountain, the atmospheric pressure drops and so too does the boiling point. **LM**

How old are diamonds?

Gina Mores

Diamonds are formed under extreme pressure and heat in the Earth's mantle, 160 kilometres underground. Between 1 and 3 billion years ago, there was a peak in diamond formation, which means most of the diamonds on Earth today date from this era. **KS**



An international body is responsible for certifying and naming any new elements

Who decides the names of newly discovered elements?

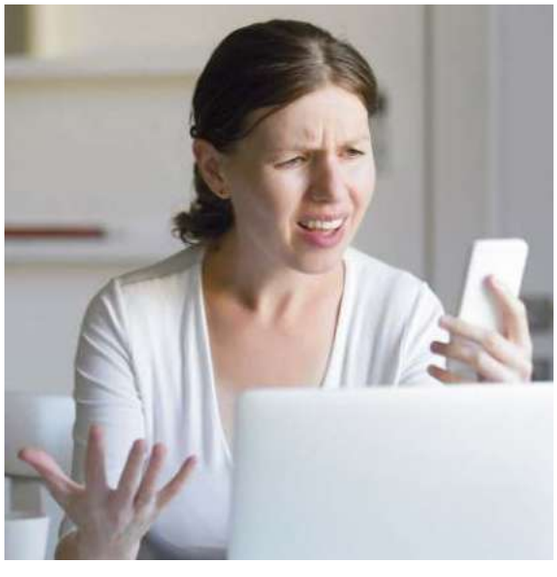
Alex Weber

The researchers who first synthesise a new element are entitled to suggest a name for it, but the final decision lies with the International Union of Pure and Applied Chemistry (IUPAC). Any new element is first assigned a temporary name until its creation has been certified. IUPAC suggests that the permanent name should take after a mythological concept, a mineral, a place or country, a property, or a scientist. **AC**

Can you get sunburn in the shade?

Eleanor Pane

UVB (Ultra Violet B) rays are responsible for burning our skin, and it's important to note that they don't have to hit us directly in order to cause damage. Just like visible light, UVB bounces off reflective surfaces, and these scattered rays can still get to our skin in the shade and cause sunburn. **LM**



Why do old phones start to lag?

Beatrice Reed

Software is the main reason your phone slows down as it ages. Your phone's hardware may remain the same as it gets older but the software you use changes a lot. Over time, as you install new apps and services your phone has to do more than when it was new, so it takes longer to do things. The operating system and apps will have been automatically updated to newer versions, too, but these are designed for new, higher specification phones and won't run as well on less powerful older models. After a while there's little choice but to upgrade. **TL**

BOOK REVIEWS

The latest releases for curious minds

Deviate

Seeing the world differently and understanding our differing perceptions

- Author: **Beau Lotto**
- Publisher: **Weidenfeld & Nicolson**
- Price: **£20 / $28**
- Release date: **Out now**

The question of how we see the world may be hard to initially grasp. When you perceive what is around you, you may notice that there are times when people experience the same thing in a different way. Do you remember the dress that famously 'broke the internet' in 2015? Was it blue or was it white? Different people saw it in different ways. How do you explain that unless you admit that each individual sees the world differently?

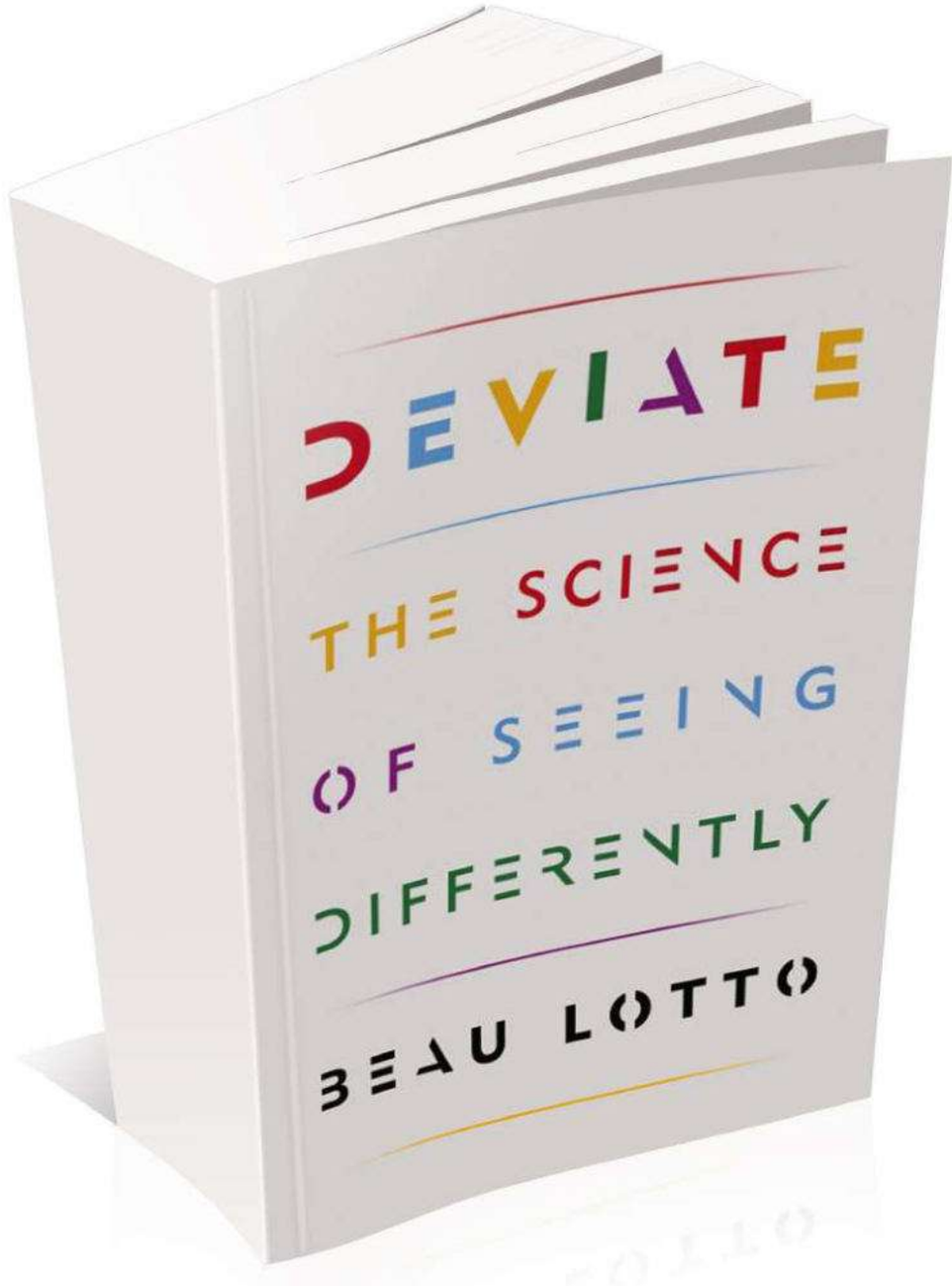
This is the idea that Beau Lotto seeks to express in *Deviate*, which takes a scientific look at perception and attempts to explain how the way we see the world is a result of our upbringing and experiences. This, at least, is fairly easy to grasp as a hypothesis – there is no doubt that the experiences you have had in the past affect the person you are today. Lotto goes further, though, explaining with case studies, science, history and more that we can reprogram our brains to recognise our reactions to perception and literally change how we think about and see the world.

It's pretty deep stuff, but Lotto writes in an engaging way that keeps the tone light and avoids getting too bogged down in the nitty-gritty of the science. His words are interspersed with odd and intriguing illustrations, and he uses italics and larger fonts to constantly draw your attention to specific words. It does at times become a little tiring, and sometimes we found ourselves having to go back and re-read sections to understand the emphasis or wanting the pace to pick up slightly and move onto other points.

The other let down in a book about perception is the lack of colour. There are optical illusions throughout that show how perception can be altered, but it feels like a missed opportunity not to feature more colourful, complex illusions.

Still, what the book does brilliantly is inspire; we have no doubt that many readers will look at the world very differently after reading it. If this was the primary purpose of the book — and we suspect it was — then it can be seen as a success.

★★★★☆



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Buonomano explores the strange ways in which our brains experience time, and whether the flow of time itself is an illusion.

The Knowledge Illusion: Why We Never Think Alone

Author: **Steven Sloman and Philip Fernback**
Publisher: **Macmillan**
Price: **£18.99 / $28**
Release date: **Out now**

Cognitive scientists Sloman and Fernback put forward their argument against the idea of truly individual thought.

How Emotions are Made: The Secret Life of the Brain

Author: **Lisa Feldman Barrett**
Publisher: **Macmillan**
Price: **£18.99 / $29**
Release date: **Out now**

Psychologist Feldman Barrett explains the latest scientific evidence on how our emotions are unique, arising as a consequence of psychological experience.

The One Device: The Secret History of the iPhone

The Apple of our eye

- Author: **Brian Merchant**
- Publisher: **Bantam Press**
- Price: **£16.99 (approx. $22)**
- Release date: **Out now**

To say that the iPhone changed the way we communicate would be an understatement — it utterly revolutionised the way we communicate on the go, packaging together the kind of functions we used to previously only be able to perform on desktops or laptops in a cohesive and reliable manner and doing so in style.

Author Brian Merchant is an editor at Motherboard, the science and technology imprint of VICE, and the methodology of his employers is very much on show here as he delves into a side of the iPhone that others previously hadn't. The chapter on Siri is particularly enlightening, as is the entry on what happens once your smartphone has bitten the dust.

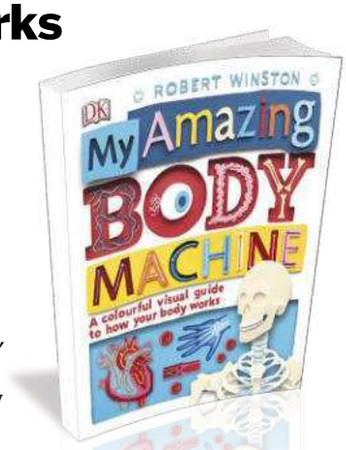
Delving deep into the iPhone's origins, this might not be what you expect — if you're expecting a Steve Jobs exposé, you won't get it. What is presented, however, is a truly eye-opening account of exactly what it takes to create a truly world-altering piece of technology.

★★★★★

My Amazing Body Machine: A Colourful Visual Guide to How Your Body Works

Who am I and how do I work?

- Author: **Robert Winston**
- Publisher: **Dorling Kindersley**
- Price: **£10.99 (approx. $14)**
- Release date: **Out now**



Dorling Kindersley has earned its place as a tried and trusted source of information for younger readers, and its latest book – a guide to the inner workings of the human body – continues in this tradition.

With illustrations from Owen Gildersleeve, *My Amazing Body Machine* explores the intricacies of the world's most impressive machine in rigorous fashion, taking in the heart and blood, lungs and breathing, the human life cycle and other important facets of the body, all presented in an informative and accessible manner.

Its target audience is clear — those of primary school age — and it never loses sight of this, keeping things colourful and crystal-clear.

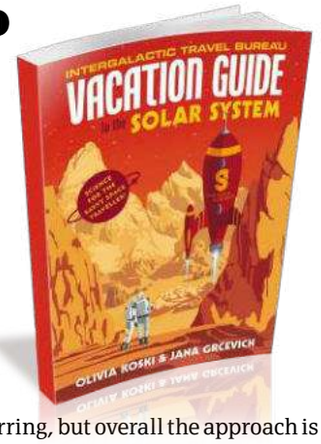
To liven things up all manner of facts are included. For instance, did you know that a pinhead-sized drop of blood contains 2.5 million red blood cells, or that sneezes blast air out at speeds of up to 160 kilometres per hour? These nuggets of trivia are just two of the many things you can find out in this book.

★★★★☆

Vacation Guide to the Solar System

Science for the savvy space traveller

- Author: **Olivia Koski and Jana Grcevich**
- Publisher: **Penguin**
- Price: **£15.27 / $20**
- Release date: **Out now**



Authors Olivia Koski and Jana Grcevich have combined a heap of science facts with a dollop of science fiction to create the ultimate hypothetical Solar System travel guide. From Mercury to Pluto, they jump forward several generations to a quirky future where space tourism is commonplace.

Some readers may feel that the book is centred around scientific facts masquerading within a playful concept. One moment we're discussing ionising radiation, the next we're developing the rules of spaceball, the Moon's equivalent to baseball. It can be somewhat jarring, but overall the approach is quite charming.

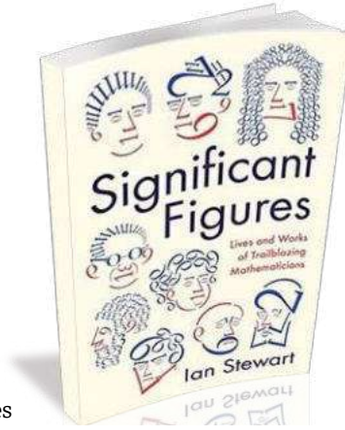
Informing readers on the serious perils of space travel is important, but highlighting the beauty of seeing the Sun change direction in the sky from the surface of Mercury, and showing how performing the 'moonwalk' dance move on Earth is likely simpler than just walking on the Moon, are very welcome additions to an educational book.

★★★★☆

Significant Figures

The lives and works of trailblazing mathematicians

- Author: **Professor Ian Stewart**
- Publisher: **Profile**
- Price: **£20 / $28**
- Release date: **Out now (UK) / 12 September (US)**



There's a popular saying that states to explain something clearly, it must first be clear in your mind. If this is the case, then the history of mathematics is as clear to author Ian Stewart as a sunny day, as his guide of prominent mathematicians brilliantly demonstrates.

An author of over 30 previous works, Stewart puts his practised hand to excellent use in *Significant Figures*. Through millennia of human history, all over the planet, the story of mathematical advancement has been unfolding. And throughout this book we're introduced to some trailblazers.

Of all the STEM subjects, mathematics is perhaps the most underrepresented in literature. It lacks the personal touch of biology and the awe of theoretical physics. But those with an interest in it will be pleased to read a book that reveals the underlying mathematical principles beneath all of our logical understanding.

★★★★★

BRAIN GYM

GIVE YOUR BRAIN A PUZZLE WORKOUT

Wordsearch

B	G	T	K	B	V	U	F	W	K	O	N	U	Y	I
O	U	F	R	O	S	T	S	F	N	D	J	D	T	M
D	I	U	L	S	A	B	C	A	L	S	S	Y	T	M
Y	D	C	A	O	D	X	G	T	A	X	E	F	K	U
C	E	O	N	N	A	R	Y	C	B	L	D	F	N	N
L	D	M	D	N	O	K	I	R	L	L	E	F	F	O
O	O	E	S	N	R	J	M	A	E	N	O	T	Z	T
C	G	T	A	J	F	N	V	T	S	T	S	I	E	H
K	R	S	I	T	F	N	X	L	X	X	T	P	X	E
O	Y	U	L	U	O	N	S	A	A	I	S	A	W	R
M	E	O	T	C	T	K	I	N	W	P	O	C	B	A
X	P	V	I	R	U	S	X	T	B	M	A	E	X	P
L	Q	L	P	K	N	A	N	I	O	W	A	Z	A	Y
R	I	R	E	F	L	E	X	S	M	O	O	R	E	X
S	R	A	S	P	B	E	R	R	Y	P	I	C	N	E

FIND THE FOLLOWING WORDS...

GUIDEDOG
SILICONVALLEY
OFFROAD
ATLANTIS
IMMUNOTHERAPY
ORGAN
HEISTS
IPACE
LANDSAIL
LAPAZ
FROST
COMETS
VIRUS
REFLEX
BOSON
BATTERY
BODYCLOCK
RASPBERRYPI
MOORE

Spot the difference

See if you can find all six changes we've made to the image on the right

Quick-fire questions

Q1 Which was the final Space Shuttle mission?

- STS-135
- STS-150
- SAS-135
- SMS-136

Q2 What is the name of Jaguar's electric sports car concept?

- I-RACE
- I-SPACE
- I-PACE
- I-CHASE

Q3 What are police dog units often called?

- P.A.W.S
- Alpha
- DoG
- K9

Q4 Which of these was a song by The Cranberries?

- Zombie
- Ghost
- Bats
- Ghoul

Q5 What is the sequence 3.14159... the start of?

- Cry
- Chi
- Why
- Pi

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9. See if you can beat the team!

5		3		1		9		
		1	9		6	3		
9	2	8	5	4	3	6	7	
		2			5	7	4	8
4	7	9	2		1		6	
6			3					9
1	9		8	5				
			1		7		9	6
8	3	7	4			1	5	

What is it?

A .....

BEAT THE TEAM...

1. Charlie 02m 49s
2. Jackie 02m 58s
3. Charlie 04m 06s
4. Duncan 04m 23s
5. Laurie 05m 31s

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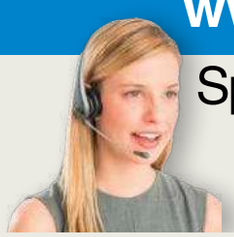

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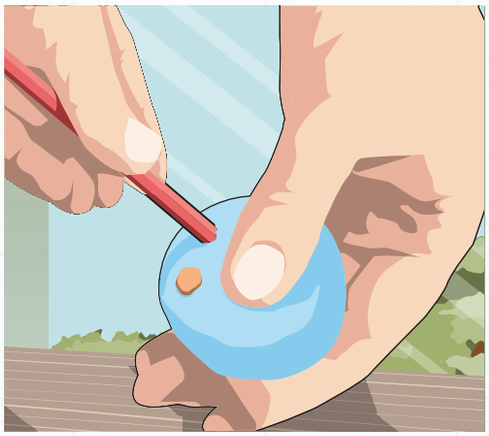
Make a planetary system

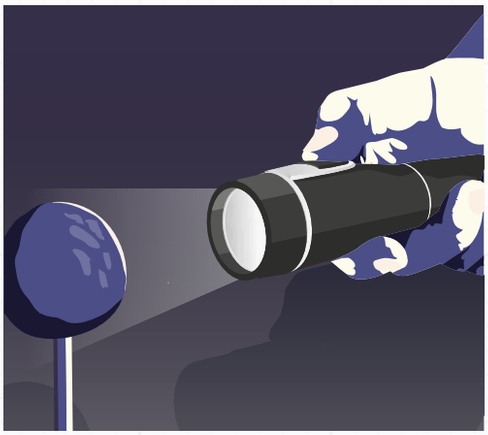
Find out how the Sun and Moon affect the Earth by creating a mini version at home

DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU



1 Make the Earth

First, let's make your planet. Roll some modelling clay into a ball around five centimetres in diameter and push a pencil into the centre of it. This will allow you to hold the 'planet' without casting shadows and also make it easier to spin it around when you're simulating the Earth. Place a blob of different coloured modelling clay onto the ball anywhere you like to represent you.

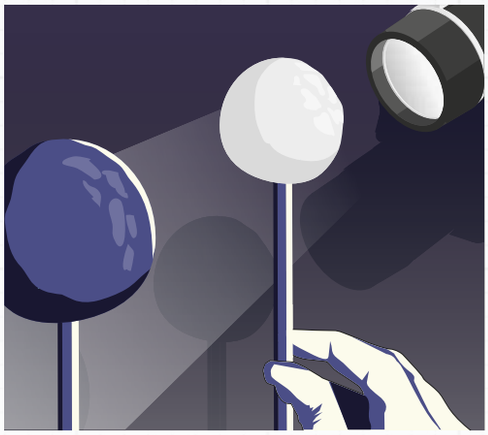


2 Activate the sun

To create our version of the Sun we'll just use a torch. The experiment works best in a fairly dark room, so turn off the lights and close the curtains. Hold the torch around 25 centimetres from the ball and keep it steady – you can place it on the edge of a surface if it's easier. You'll notice that just over half of your planet is light, with the back of the planet being much darker.

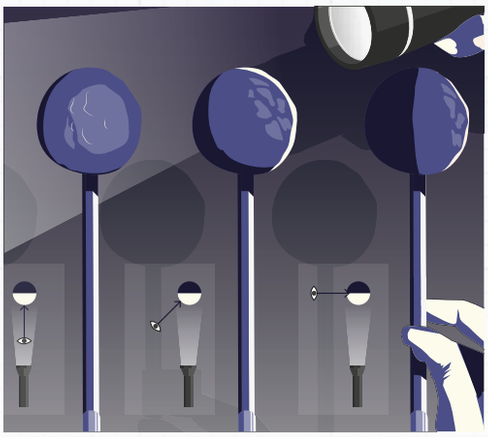
3 Spin and rotate

Start to slowly rotate the pencil under the planet. You'll see the blob of clay that you stuck on slowly moves from the darker side to the lighter side. This simulates how the Sun shines on the Earth as it spins. When the coloured blob of clay is half in light and half in darkness this represents sunrise on Earth. Then, when it is rotated again, it will do the same to represent sunset.



4 Create the Moon

Next, we'll test out the Moon in the same way. Get some more modelling clay and make it into a ball around three centimetres in diameter. Push another pencil into it, then try moving it around the Earth. What happens when the Sun, Moon and Earth all align? When the Moon is either fully in the shadow of the Earth, or casts a shadow *on* the Earth, it's called an eclipse.



5 Test moon phases

You can also use your Moon to see how lunar phases work. Hold your Moon model still in front of the torch. Stand with the torch over your shoulder and you'll see a full circle – like a Full Moon. Move around so that you are at an angle to the torch and you'll see that the shape appears to change. This is why, when we look at the Moon in the sky, it always looks like a different shape.

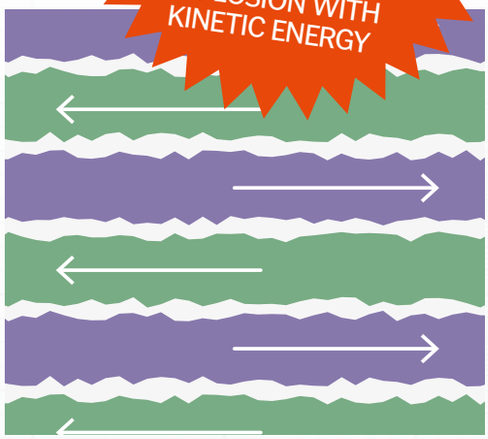
"You can use your Moon model to see how lunar phases work"

In summary...

The movements of the Moon around the Earth and the Earth around the Sun are very complex and affect a lot of different things, including seasons, tides and temperatures. This test shows you how sunrises and sunsets work, why the day lasts longer than the night, and why the Moon looks different every night.

Test friction

Discover the power of friction with this interesting test



1 Weave it together
Find two equally sized books, each with at least 200 pages. Open one and rub two pages together. You'll notice that it's not difficult – that's because the force of friction is only small between the pages. Start weaving the two books together, one page at a time. Open a page in one book, then place a page from the other book onto it, around three inches in. Do this until the whole book is weaved together.

2 Try to pull
Grip the books tightly with two hands, making sure you're not holding onto the pages of the other book that are weaved into yours. Have a friend do the same thing with the other book, then try to pull the two books apart. Can you do it? Even if you did manage it, you'll notice how difficult it was. If you've used large books, like two telephone directories, you'll probably find that you can't pull them apart.

3 Friction in action
Each page of the book looks smooth, but paper is actually very bumpy if you look closely. When the bumps overlap with each other and are pressed together by the other pages of the two books, friction makes it very difficult to move the paper. This is happening between every page – that's a lot of friction! The smaller forces add up and make a much larger one.

"Each page looks smooth, but paper is actually very bumpy"

In summary...
The small force of friction you felt when you rubbed the two pages together in step 1 might not feel like much, but when there are over 100 pages pressed together it adds up! It soon becomes impossible to pull the books apart. A large enough book would support a human's weight!

NEXT ISSUE
MAKE METEOR IMPACT CRATERS
CREATE A LOLLY STICK EXPLOSION WITH KINETIC ENERGY

WIN!

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Which of these was NOT a Space Shuttle?

a) **Discovery**
b) **Endeavour**
c) **Franklin**

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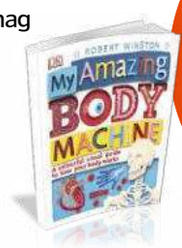

Letter of the Month

Solar panels in Australia

Dear **HIW**,
I have just received my first issue of HIW and am glad to say that it was the 100th issue! My name is Xavier and I am 12 years old, I live in Yeppoon, Queensland. I have been reading HIW for many years – my English Grandmother gave me my first issue when I was eight.

Here is a photo of me on my house's roof. I am next to all of the solar systems that we have. We have a solar hot water, a row of 12 solar panels, and solar pipe heating for our swimming pool. If you look closely, you can also see our neighbour's solar system and also out in the ocean you can see Great Keppel Island, which is part of the Great Barrier Reef.

I took this photo on the roof because I was reading the magazine and saw the article on electricity (pg 19) and thought it would be cool to show all of our electricity production. Thanks again for the magazine. I look forward to reading more about how things work.
Xavier Craggs

Thanks so much for your letter! We are really impressed with the solar panels you have on your roof and we're happy you are enjoying reading our magazine. It must be great living so close to the Great Barrier Reef. Thanks again for writing to us, Xavier!

Good eyesight is essential for birds to fly safely

Bobbing Birds

Dear **HIW**,
Why do (most) birds 'bob' their heads?
Eti

Hi Eti! Great question! Lots of birds, such as pigeons, seem to bob their heads when they are walking, though scientists aren't exactly sure why they do.

In fact, rather than bobbing their heads, they move their bodies forward but leave their heats behind, then thrust their heads forward past their bodies. This is thought to help improve their vision while foraging. For example, when their heads are still, birds's vision is stabilised and so moving objects in the background become more apparent. But, when they move their heads, their depth perception improves by providing a view of a nearby object from two slightly different perspectives.

Scientists have tested this by putting birds on treadmills, and they noticed they don't bob their heads if their environment isn't moving. Humans do this by slightly twitching our eyes because we are are instinctively tracking things that move around us. If we didn't, everything would look really blurry.

Secrets of smells

Dear **HIW**,
Why do foul odors remain when others fade away?
Connie D Starkey

Thanks for the question Connie! Often, bad smells are things that have been wired into our brains to be suspicious about, and therefore we are often more sensitive to particular smells and can detect them even in small amounts.

For example, rotten food could make us sick, so we are more sensitive to these odors. Typically we're disgusted by them as a way to make sure we avoid the source.

Bad odors tend to hang around if the compounds responsible for them have a higher molecular weight, making it harder for them to dissipate.

Some aroma compounds, such as those in garlic or tobacco, are particularly pungent. These smells seem to linger no matter how hard you may wash your hands, because they are actually able to penetrate the skin.

Humans can detect around 1 trillion distinct smells

What's happening on... social media?

We asked our followers what they would create if they could genetically engineer anything...

What about a modification that stopped or slowed down aging?
Lauren Hills

Remove HIV from the chromosomes of infected people
Alistair Gordon Shaw

A plant that grows cheese
Grace Holloway

Gut flora that produces insulin for people with diabetes.
Samuel Levesque

Here's the latest from some of our favourite accounts...

Ever wondered if events like #Eclipse2017 happen on other planets? They definitely do in the Saturn system!
@CassiniSaturn

Pics of SpaceX spacesuit developed for NASA commercial crew program coming out next week.
@elonmusk

Moon's shadow landfalls Oregon. Crosses USA at 1800mph. Exits SCarolina. Touches no other country. Behold 'Muuurica's Eclipse
@neiltyson

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Issue 104 on sale 5 October 2017

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THE LATEST PROTOTYPES GETTING OFF THE GROUND TO MAKE SCI-FI TRAVEL A REALITY

The real Wild West: what life was like in the Frontier

How tech is making our homes smarter, safer and greener

Uncovering the hidden history of England's Jurassic Coast

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MORE THAN **320,000** DIFFERENT VIRUSES INFECT MAMMALS

THE SPACE SHUTTLE PROGRAM COMPLETED

135 FLIGHTS

BEFORE RETIRING FROM SERVICE

1 BILLION

ESTIMATED NUMBER OF COMETS IN THE SOLAR SYSTEM

IT TAKES JUST 4 SECONDS FOR THE JAGUAR I-PACE CONCEPT TO REACH 100KPH

181MN KILOGRAMS

OF CRANBERRIES ARE CONSUMED BY AMERICANS EVERY YEAR

305 METRES

THE RECORD FOR THE DEEPEST UNDERWATER DIVE BY A HUMAN

15%

OF THE POPULATION SLEEPWALK

202.9KPH

THE FASTEST RECORDED SPEED FOR A LAND YACHT

0°C

THE TEMPERATURE AT WHICH FROST WILL FORM

THE WEDDELL SEAL HAS ONE OF THE STRONGEST DIVE REFLEXES

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